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TECHNICAL MANUAL

INTERMEDIATE MAINTENANCE AND DEPOT LEVEL MAINTENANCE INSTRUCTIONS

AERONAUTICAL EQUIPMENT WELDING

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Total number of pages in this publication is 284 consisting of the following:

Page No.	#Change No.
Title	0
A	0
i – viii	0
1–1 – 1–2	0
2–1 – 2– 19	0
2–20 Blank	0
3–1 – 3–52	0
4–1 – 4–48	0
5–1 – 5–46	0
6–1 – 6–64	0
7–1 – 7–2	0
A–1 – A–6	0
B–1 – B–15	0
B–16 Blank	0
GLOSSARY 1– GLOSSARY 17	0
GLOSSARY 18 Blank	0

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont.)

LIST OF ILLUSTRATIONS (Cont.)

LIST OF TABLES

LIST OF TABLES (Cont.)

LIST OF TECHNICAL PUBLICATIONS DEFICIENCY REPORTS INCORPORATED

REPORT CONTROL NUMBER(RCN)	LOCATION
N39788-97-0074	Pg. i
N09251-97-0134	Pg. A
N44329-98-0139	Pg. 2-2
22202-98-0139	Pg. 5-2

SECTION I.
INTRODUCTION

1.1 PURPOSE.

This welding manual is intended to be used with maintenance, repair and overhaul manuals. This is a general series manual and is intended to be used in conjunction with specific maintenance/repair/overhaul manuals or engineering documents for aircraft, aircraft components and support equipment.

1.2 SCOPE.

This technical manual is published for use by personnel, at both Intermediate Level and Depot Level for welding and other metal joining operations in the manufacture and maintenance of material.

e. All Intermediate and Depot level aircraft and support equipment welding shall be in accordance with data contained in this manual unless otherwise specified. When specific engineering drawings or overhaul instructions conflict with this manual the specific document shall apply.

f. The responsibility for this manual lies with NAVAVNDEPOT North Island, Code 43400. All activities using it are invited to submit recommended changes, corrections or deletions in accordance with procedures set forth by OPNAVINST 4790.2 series. T.O. 00–5–1 and Army Regulations 25–30.

1.3 DESCRIPTION, BACKGROUND INFORMATION.

a. This manual contains information as outlined below:

(1) Basic welding processes

(2) Characteristics, identification and heat treatment of various metals.

NOTE

Please refer to T.M. 43–0106/T.O. 1–1A–9/NA 01–1A–9 for further information.

(3) Classification of steels

(4) Welding/brazing and cutting processes

(5) Safety precautions

(6) Certifications of welders

(7) Welding symbols

b. Appendix A contains a list of welding symbols and codes.

c. Appendix B contains a list of specific base metals for base metal groups.

1.4 WARNINGS AND CAUTIONS APPLICABLE TO HAZARDOUS MATERIALS.

Warnings and cautions for hazardous materials listed in here are designed to apprise personnel of hazards associated with such items when they come in contact with them by actual use. Additional information related to hazardous materials is provided in each service's program manual and the DOD 6050.5 Hazardous Materials Information System (HMIS) series publications. Consult your local safety and health staff concerning specific personnel protective requirements and appropriate handling and emergency procedures.

1.5 WELDING THEORY.

1.5.1 General.

a. Welding is any metal joining process wherein coalescence is produced by heating the metal to suitable temperatures, with or without the application of pressure and with or without the use of filler metals. Basic welding and torch brazing processes are described and illustrated in this manual.

1.5.2 Theory.

a. Metals.

(1) Metals are divided into two classes, ferrous and nonferrous. Ferrous metals are those in the iron class and are magnetic in nature. These metals consist of iron, steel and alloys related to them. Nonferrous metals are metals that con-

tain either none or very small amounts of ferrous metals and are generally divided into the aluminum, copper, magnesium, lead and similar groups.

(2) Welding processes for these metals are varied and information contained in this manual covers theory and application of welding for many types of metals.

SECTION II.
SAFETY

2.1 SAFETY PRECAUTIONS IN WELDING OPERATIONS.

WARNING

To prevent injury or death, each service's safety and health program must be followed. Section II contains generalized information extracted from safety and health related documents. Personnel shall follow their service safety and health program (OPNAVINST 5100.23, AFOSH, USACOE 385–1, and national consensus standards).

2.2 SAFETY SUMMARY.

The following are general safety precautions that are not related to any specific procedures and therefore do not appear elsewhere in this publication. These are recommended precautions that personnel must understand and apply during all phases of operation and maintenance.

2.2.1 Hazardous Materials. Use all cleaning solvents, fuels, oils, adhesives and epoxies, and catalysts in a well ventilated area. Avoid frequent and prolonged inhalation of fumes. Concentrations of fumes of many cleaners, adhesives and esters are toxic and will cause serious deterioration of the body nervous systems and possible death if breathed frequently. Avoid frequent or prolonged exposure to the skin. Wash thoroughly with soap and warm water as soon as possible after completing use of such materials. Take special precautions to prevent material from entering the eyes. If exposed, rinse the eyes in an eye bath fountain immediately and report to a physician.

2.2.1.1 Thorium. Thorium is a naturally occuring radionuclide contained in various manufactured items such as incandesent gas mantles, welding rods, lenses and aircraft parts. Manufactured items exempted in 10CFR 40.13 or authorized by general license in 10 CFR 40.22 do not require a NRMP. Grinding of thoriated electrodes can produce surface contamination.

2.2.1.1.1 Thoriated Tungsten Welding Electrodes.

REQUIREMENTS:

a. Isolate grinding areas by providing a separate grinding booth or room.

b. Provide exhaust ventilation for the grinding booth or room.

c. Clean the grinding area after each shift, when used, by vacuum cleaning or wiping.

d. Dispose of grinding dust, chips and cleaning rags as normal waste materials as it is generated.

e. Use wet belt grinding machines to contain dust.

f. Ensure adequate ventilation by welding in large open areas whenever possible.

g. In enclosed or restricted areas, provide dust respirators (3M Model 9940 or equivalent) for workers or provide adequate ventilation by hood or portable duct. Hoods, enclosures and portable ducts shall be designed and operated to the requirements of the latest edition of “Industrial Ventilation”, American Conference of Governmental Industrial Hygienists. The face velocity for portable ducts shall be at least 1,500 feet per minute.

2.2.2 Flammables. Keep all cleaning solvents, oils, esters and adhesives away from open flame space heaters, exposed element electric heaters, sparks or flame. Do not smoke when using; or in the vicinity of flammable materials, or in areas where flammables are stored. Provide adequate ventilation to disperse concentrations of potentially explosive fumes or vapors. Provide approved containers for bulk storage of flammable materials and dispensers in the working areas. Keep all containers tightly closed when not in use.

2.2.3 Compressed Air. Air pressure used in work areas for cleaning or drying operations, shall be regulated to 29 psi or less. Use approved safety equipment (goggles/face shield) to prevent injury to the eyes. Do not direct the jet of compressed air at self or other personnel or so that refuse is blown onto adjacent work stations. If additional air pressure is required to dislodge foreign materials from parts, ensure that approved safety equipment is worn, and move to an isolated area. Be sure that the increased air pressure is not detrimental or damaging to the parts before applying high pressure jets of air.

2.2.4 Heat and Cold**.** Use thermally or similar insulated gloves when handling either heated or chilled parts to prevent burns or freezing of hands. Parts chilled to super–cold (–40°F to –65°F) temperatures can cause instant freezing of hands if handled without protective gloves. Adequate precautions should be taken to prevent maintenance personnel from inadvertently coming in contact with the hot surfaces.

2.2.5 Aeronautical and Support Equipment (SE). Improperly maintained support equipment can be dangerous to personnel and can damage parts. Observe recommended inspections to avoid unanticipated failures. Use SE only for the purpose for which it was designed, and avoid abuse. Be constantly alert for damaged equipment and initiate appropriate action for approved repair immediately. When installing lift/support fixtures and rail set use only the attachment hardware items (nuts, bolts, screws, pins, etc.) supplied for specific use with the SE. Substitute items shall not be used.

2.2.6 Maintenance Procedures. Wear safety glasses or other appropriate eye protection at all times. Do not allow safety wire or wire clippings to fly from cutter when removing or installing wire. Do not use fingers as guides when installing parts or to check alignment of holes. Use only correct tools and fixtures, and use as recommended. Avoid shortcuts, such as using fewer than recommended attaching bolts, shorter bolts, or bolts of incorrect quality. Heed all warnings in the manual text to avoid injury to personnel or damage to equipment.

2.2.7 General Safety Precautions.

NOTE

Authority to weld on a particular aircraft, aircraft part or any support equipment must be obtained before any welding/brazing operation can be attempted. Authorization can be found in applicable maintenance manuals and directives.

a. Care should be taken in handling any type of welding equipment to prevent personnel injury from fire, explosions, or harmful agents. Safety precautions listed below must be strictly observed by workers who weld or cut metals.

b. Do not permit unauthorized persons to use welding or cutting equipment.

c. Do not weld in a building with wooden floors, unless the floors are protected from hot metal by means of sand, or other fireproof material. Be sure that hot sparks or hot metal will not fall on the legs and feet of the operator or on any welding equipment components.

d. Remove all flammable material such as cotton, oil, gasoline, etc., from the vicinity of welding.

e. Before welding or cutting, warn those in close proximity who are not protected by proper clothing or goggles.

f. Remove assembled parts that may become warped or otherwise damaged by the welding process.

g. Do not leave hot rejected electrode stubs, steel scrap, or tools on the floor about the welding equipment. These may cause accidents.

h. Keep a suitable fire extinguisher conveniently located at all times.

i. Mark all hot metal after welding operations are completed. Soapstone or chalk may be used for this purpose.

j. Contact lenses shall not be worn during welding/hot work operations. No contact lenses shall be worn while using a respirator.

k. No matches, cigarette lighters, or other flame producing devices, shall be carried on your person during welding/hot work operations.

2.2.8 Protective Clothing and Equipment. Protective clothing and equipment must be worn during welding operations. During all oxyacetylene welding and cutting processes operators shall use welding goggles or glasses (with side shields) (figure 2–2) equipped with a suitable filter lens to protect the eyes from intense light levels, heat, glare, and flying fragments of hot metal (table 2–1). The Shielded Metal Arc Welding (SMAW) and Flux Cored Arc Welding (FCAW) processes require the chipping of slag after the weld has been deposited. Operators shall use a welding hood for chipping slag. All other electric welding processes require welding hoods equipped with a suitable filer glass to protect against the intense ultraviolet and infrared rays (figure 2–1). When others are in the vicinity of the electric welding process the area must be screened so that the arc cannot be seen either directly or by reflection from glass or metal.

2.2.8.1 Helmets and Shields.

a. Welding arcs are intensely brilliant lights. They contain a proportion of ultraviolet light which may produce eye damage. For this reason, no one should look at the arc with the naked eye within a distance of 50 feet. The brilliance and danger of the light depends on the welding method, current, and material being welded. Operators, fitters, and others working nearby need protection against arc radiation. Since arc radiation decreases rapidly in intensity with distance, the closest workers need the most protection.

b. The welder needs a helmet to protect the eyes and face from harmful light and particles of hot metal. The welding helmet (figure 2–1) is generally constructed of a pressed fiber insulating material. It has an adjustable headband that makes it usable by persons with different head sizes. The helmet is dull black in color to minimize reelection and glare produced by the intense light. The helmet fits over the head and can be swung upward when not welding. The chief advantage of the helmet is that it leaves both hands free, making it possible to hold the arc and weld at the same time.

c. The hand shield (figure 2–1) provides the same protection as the helmet except that it is held in position by the handle. This type of shield is frequently used by an observer or a person who welds for a short period of time.

NOTE

The colored glass must be manufactured in accordance with specifications detailed in the ”National Safety Code for the Protection of Hands and Eyes of Industrial Workers”, issued by the National Bureau of Standards, Washington DC, OSHA Standard, 29CFR 1910.252 Welding, Cutting and Brazing, American National Standards Institute Standard (ANSI) Z87.l 1979, ”American National Standard Practice for Occupational and Educational Eye and Face Protection”.

d. The protective welding helmet has a glass window, containing a filter lens specifically designed to prevent flash burns and possible eye damage through absorption of the infrared and ultraviolet rays produced by the arc. Lenses come in various optical densities with different shades to be used when welding various metals with different methods (table 2–1). The color of the lenses, usually green, blue, or brown, is an added protection against the intensity of white light or glare. Colored lenses make it possible to see the metal more clearly and weld more efficiently.

e. Gas metal–arc (GMAW) welding requires darker filter lenses than shielded metal–arc (stick) welding, because it produces less smoke to absorb arc rays.

f. Do not weld with cracked or defective shields because penetrating rays from the arc may cause serious burns. Be sure that the colored glass plates are the proper shade for arc welding. Protect the colored glass plate from spatter by using a cover glass. Replace these cover glasses when damaged or spotted by molten metal spatter.

g. Face shields and safety glasses shall be worn during chipping and grinding operations.

h. In some welding operations, the use of mask–type respirators is required. Helmets with the ”bubble” front design can be adapted for use with respirators.

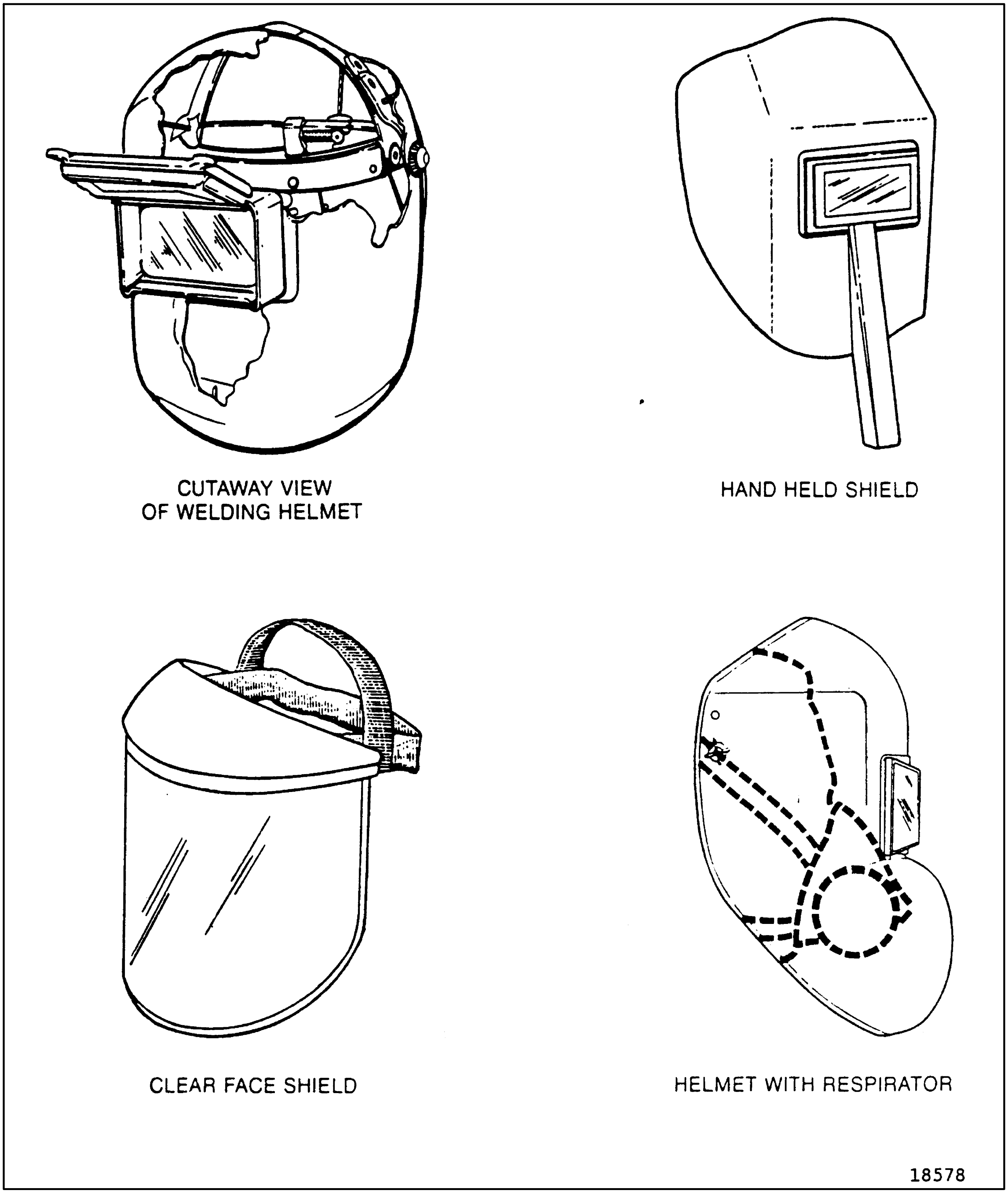


Figure 2-1. Welding Helmets and Shields

2.2.8.2 Protective Clothing. Personnel exposed to the hazards created by welding, cutting or brazing operations shall be protected by personal protective equipment within OSHA standard 29CFR 1910.137 Personal Protective Equipment. Appropriate protective clothing (figure 2-3) required for any welding operation will vary with the size, nature and location of the work to be performed.

a. Cotton clothing should be worn during all welding operations to protect welder from metal spatter and ultraviolet light. All other clothing such as jumpers or overalls should be reasonably free from oil or grease.

b. Flameproof aprons or jackets made of leather, or other suitable material shall be worn for protection against spatter of molten metal, radiated heat, and sparks. Capes or shoulder covers made of leather or other suitable materials should be worn during overhead welding or cutting operations. Leather skull caps may be worn under helmets to prevent head burns.

c. Sparks may lodge in rolled-up sleeves or pockets of clothing, of cuffs or overalls or trousers. Therefore sleeves and collars should be kept buttoned and pockets eliminated from the front of overalls and aprons. Trousers or overalls should not be turned up on the outside. For any welding operation, lace-up, high boots and safety toes (such as those conforming to MIL-B-24911, Boots, Aircrew, or MIL-STD-AA-1803 Boots, Safety, Men's) shall be worn. No low cut boots or shoes allowed. In production work, a sheet metal screen in front of the worker's legs can provide further protection against sparks and molten metal in cutting operations.

d. Flameproof gauntlet gloves, preferably of leather, should be worn to protect the hands and arms from the rays of the arc, molten metal spatter, sparks, and hot metal. Leather gloves should be of sufficient thickness that they will not shrivel from heat, burn through, or wear out quickly. Do not allow oil or grease to come in contact with the gloves because this will reduce their flame resistance and cause them to be readily ignited or charred.

2.2.9 Protective Equipment.

a. Where there is exposure to sharp or heavy falling objects or a hazard of bumping in confined spaces, hard hats or head protectors should be used.

b. For welding and cutting, overhead, or in confined spaces, ear protection is sometimes desirable.

c. When welding in any area, the operation should be adequately screened to protect nearby workers or passers-by from the glare of welding. The screens should be so arranged that no serious restriction of ventilation exists. The screens should be so mounted that they are about two feet above the floor unless the work is performed at such a level that the screen must be extended nearer the floor to protect adjacent worker. The height of the screen is normally six feet but may be higher depending upon the situation. The screens, if metal, should be painted with a finish of low reflectivity. If other materials are used, the surface should be of low reflectivity.

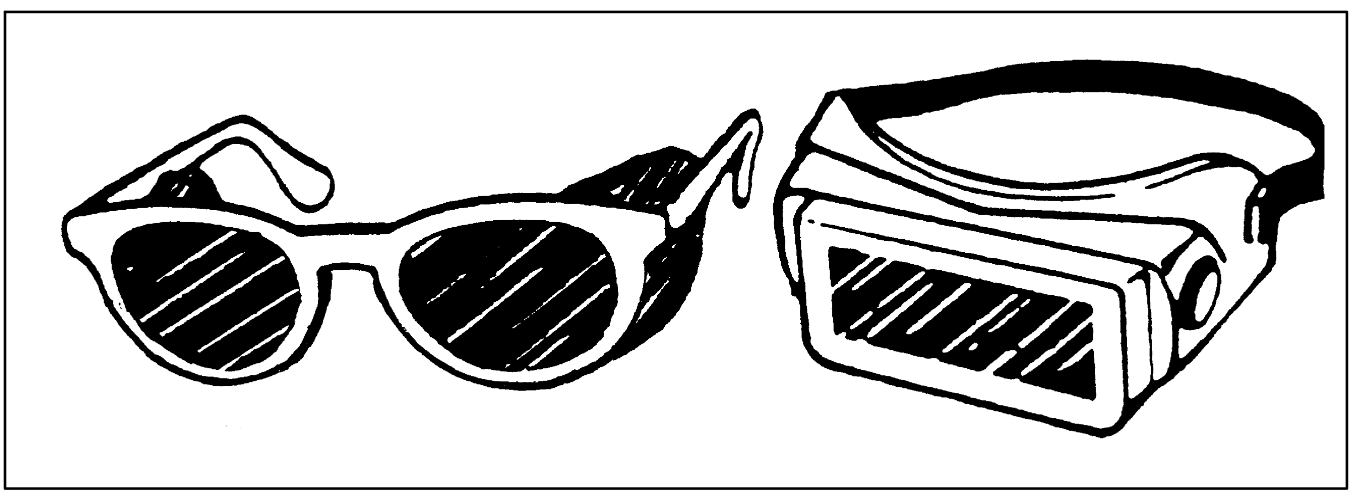


Figure 2-2. Welding Goggles and Glasses

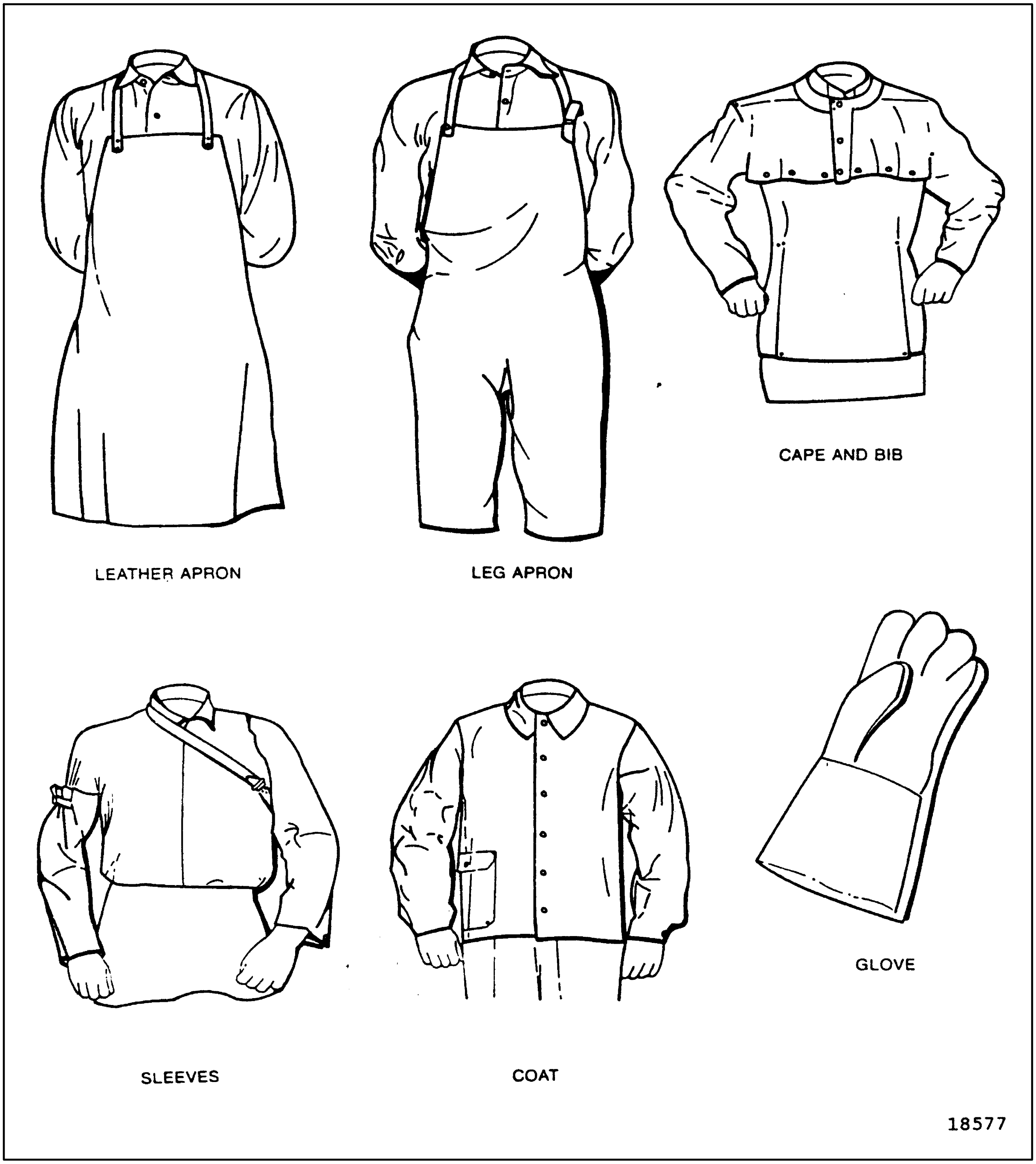


Figure 2-3. Protective Clothing

(1) During the welding and cutting operations sparks and molten spatter are formed, and sometimes fly appreciable distances. For this reason welding or cutting should not be done near flammable materials, unless every precaution is taken to prevent ignition.

(2) Whenever possible flammable materials attached to or near equipment requiring welding, brazing, or cutting should be removed. If removal is not practical, a suitable shield of authorized heat resistant material should be used to protect the flammable material. Fire extinguishing equipment for any type of fire that may be encountered must be available.

2.2.10 FIRE HAZARDS.

a. Fire prevention and detection are the responsibility of welders, cutters, and supervisors. The elaboration of basic precautions to be taken for fire prevention during welding or cuttting is outlined in the Standard for Fire Prevention in Use of Cutting and Welding Processes, National Fire Protection Association Standard 51B. Some of the basic precautions for fire prevention in welding or cutting work are given below:

(1) When welding or cutting parts of vehicles, the oil pan, gasoline tank, and other parts of the vehicle should be considered fire hazards and effectively shielded from sparks, slag, and molten metal.

2.2.10.1 HEALTH PROTECTION AND VENTILATION. The following requirements have been established to provide guidelines and procedures to maximize protection for welders and torch brazers exposed to flammable conditions, confined areas, hazardous materials and contamination.

2.2.10.2 VENTILATION FOR WELDING AND BRAZING. It is recognized that in individual instances other factors may be involved in which case ventilation or respiratory protective devices should be provided as needed to meet the equivalent requirements of this section. Such factors would include: (1) atmospheric conditions; (2) heat generated; (3) presence of volatile solvents; in all instances, however, the required health protection, ventilation standards and standard operating procedures for new as well as old welding operations should be coordinated and cleared through the Safety Officer, Gas Free Engineer/Fire Inspector and Public Health Officer as required.

NOTE

Specific procedures are covered by the Navy Gas Free Engineering Program as detailed in the Fuel Cell Manual, NAVAIR 01–1A–35.

2.2.10.3 CONCENTRATION OF TOXIC SUBSTANCES. Local exhaust or general ventilating systems shall be provided and arranged to keep the amount of toxic fumes, gas or dust below the acceptable concentration of toxic dust and gases: American National Standard Institute Standard Z49.1–1983 the latest Threshold Limit Values (TLV) of the American Conference of Governmental Industrial Hygienists; or the exposure limits as established by Public Law 91–596, Occupational Safety and Health Act. Compliance shall be determined by sampling of the atmosphere. Samples collected shall reflect the exposure of the persons involved. When a helmet is worn, the samples shall be collected under the helmet.

2.2.10.4 RESPIRATORY PROTECTIVE EQUIPMENT. Individual respiratory protective equipment should be well maintained. Only respiratory protective equipment approved by the US Bureau of Mines, National Institute of Occupational Safety and Health or other governmental approved testing agency shall be utilized. Guidance for selection, care and maintenance of respiratory protective equipment is given in Practices for Respiratory Protection, American National Standard Institute Standard 788.2, TB MED 223 and AFOSH 48–1. Respiratory protective equipment should not be transferred from one individual to another without being cleaned.

Table 2-1. Lens Shades For Welding And Cutting

Method	Electrode Diameter, Inch	Metal Thickness, Inch	Lens* Number
Welding			
SMAW	1/16 to 5/32	----	10
	3/16 to 1/4	----	12
	5/16 to 3/8	----	14
GMAW	1/16 to 5/32	Ferrous	10/11
	----	Nonferrous	11
GTAW	----	Ferrous	10/11
	----	Nonferrous	10/11
Atomic Hydrogen	----	----	10 to 14
Carbon-arc	----	----	10/12
Air Arc Cutting	5/32 to 1/4 carbon	----	10 to 14
Gas Torch	----	to 1/8	4 or 5
	----	1/8 to 1/2	5 or 6
	----	over 1/2	6 or 8
Brazing Torch	----	----	3 or 4
Cutting Torch	----	to l	3 or 4**
	----	1 to 6	4 or 5
	----	over 6	5 or 6
Soldering Torch	----	----	2

*Too dark or too light lens cause eyestrain.
**Goggles need sideshields.

Table 2-2. Required Exhaust Ventilation

Welding Zone	Minimum Air Flow, Cubic Feet/Minute*	Duct Diameter Inches**
4 to 6 inches from arc or torch	150	3
6 to 8 inches from arc or torch	275	3-1/2
8 to 10 inches from arc or torch	425	4-1/2
10 to 12 inches from arc or torch	600	6-1/2

* When brazing with cadmium bearing materials or when cutting on such materials increased rates of ventilation may be required.
** Nearest half-inch duct diameter based on 4,000 feet per minute velocity in pipe.

2.2.10.5 VENTILATION FOR GENERAL WELDING AND CUTTING. Mechanical ventilation shall be provided when welding or brazing is performed:

a. In a space of less than 10,000 cubic feet per welder.

b. In a room having a ceiling height of less than 16 ft.

c. In confined spaces or where the welding space contains partitions, balconies, or other structural barriers to the extent that they significantly obstruct cross ventilation.

2.2.10.6 MINIMUM RATE. Such ventilation shall be at the minimum rate of 2,000 cubic feet per minute per welder, except where local exhaust hoods and boots as in paragraph 2.3, or airline respirators approved by the US Bureau of Mines, National Institute of Occupational Safety and Health or other governmental approved testing agency may be used. When welding with rods larger than 3/16-inches in diameter, the ventilation shall be higher as shown in the following table:

Rod diameter (inches)	Required Ventilation (cfm)
1/4	3500
3/8	4500

Natural ventilation is considered sufficient for welding or cutting operations where the restrictions in paragraph 2.2.10.7 are not present.

2.2.10.7 LOCAL EXHAUST VENTILATION. Mechanical local exhaust ventilation may be by means of either of the following:

a. Hoods. Freely movable hoods intended to be placed by the welder as near as practicable to the work being welded and provided with a rate of air flow sufficient to maintain a velocity in the direction of the hood to 100 linear feet per minute in the zone of welding when the hood is at its most remote distance from the point of welding. The rates of ventilation required to accomplish this control velocity using a 3–inch wide flanged suction opening are shown in table 2–2.

b. Fixed Enclosure. A fixed enclosure must have a top and not less than two sides which surround the welding or cutting operations and a rate of airflow sufficient to maintain a velocity away from the welder of not less than 100 linear feet per minute. Downdraft ventilation tables require 150 cubic feet per minute per square foot of surface area. This rate of exhausted air shall be uniform across the face of the grill.

2.3 WELDING IN CONFINED SPACES.

CAUTION

All welding spaces must be classified by a Gas Free Engineer, Qualified Navy Aviation Gas Free Engineering Technician. Air Force should refer to AFOSH 127–100 and AFOSH 127–25. The controlling documents for gas free engineering program are: NAVSEA 56470–AA–SAF–010 (ashore) and NAVSEA 59086–CH–STM–030 (afloat). The controlling document for the Aviation Gas Free Engineering (AVGFE) program is NAVAIR 01–1A–35.

NOTE

Paragraphs 2.3.1.1 through 2.3.1.4 are applicable to Air Force.

2.3.1 GAS FREE ENGINEERING CLASSIFICATION CRITERIA. The following criteria are used to classify confined or enclosed spaces including those with open tops, but with a depth or configuration sufficient to restrict the natural movement of air, and those which are normally closed with limited or restricted openings for entry and exit. Confined or enclosed spaces are classified based on existing or potential hazards as defined in table 2–3.

2.3.1.1 ENTRY/WORK RESTRICTIONS. The following restrictions apply to entry and work in or on Class I and Class II confined or enclosed spaces.

2.3.1.2 CLASS I SPACES. Entry into and work in or on class I spaces shall not be permitted under normal operations and is authorized only under the following circumstances:

a. Entry into Class I spaces is authorized only in cases of extreme emergency such as rescue efforts, emergency repairs, etc. In the event of any such emergency entry or work, personnel entering the space shall be equipped with the following:

(1) Air–supplied respirator, MIL–SPEC GGG–M–125/1B.

(2) Harness suitable to permit extraction of the person from the space.

(3) Lifeline securely attached to the harness.

(4) Other necessary personal protective equipment required by the conditions and exposure.

(5) Communication shall be maintained between the person entering the space and safety observer outside the space.

(6) Emergency rescue personnel, equipped with the above listed equipment, and any additional equipment which may be necessary to effect a rescue shall be stationed immediately outside the entry to the confined/enclosed space.

(7) Explosion–proof lights only shall be used in fuel cells.

b. Cold Work. Cold work may be performed on the exterior areas of a Class I space, from outside the space, provided that the work performed does not generate heat or other ignition sources which may cause ignition of atmosphere within the space.

c. Hot Work. Hot work may be performed on the exterior areas of a Class I space from outside the space, when the atmosphere inside the space does not contain flammable, explosive, or oxygen enriched atmosphere. The Class I classification of the space in this case, would be based on oxygen depletion or the presence of toxins, and would include spaces which are inerted, pressed up or a combination thereof.

2.3.1.3 CLASS II SPACES. Contamination in Class II spaces shall be identified and removed to the maximum degree possible by cleaning, ventilating, or recommended methods prior to entry or work.

2.3.1.4 HOT WORK. The following paragraphs apply to all hot work performed in confined or enclosed spaces, or hot work performed on closed structures such as pipes, fuel cells, ducts, tubes, jacketed vessels and similar items. Air Force shall use AFOSH 91–5.

2.3.1.5 HOT WORK OPERATIONS. Hot work for the purpose of gas free engineering, includes any work that produces heat by any means, of a temperature of 400° F (204° C) or more, in the presence of flammables or flammable atmospheres, such as:

a. Flame Heating.

b. Welding.

c. Brazing.

WARNING

Do not perform hot work without specific authorization of activity Gas Free Engineer (GFE) or hot work certified Aviation Gas Free Engineering Technician (AVGFET).

Inerting shall not normally be used as a means to permit hot work on any component of a fuel system that contains aviation gasoline or Jet Petroleum (JP) fuels.

2.3.1.6 SPACE CLEANING. Prior to commencing hot work in a confined or enclosed space, the space shall be tested, inspected, cleaned, and ventilated as required by the provisions of this manual and the applicable aircraft MIM.

2.3.1.7 FIRE PREVENTION. A fire guard shall be posted at the work site when hot work is to be conducted in the presence of combustible materials or flammable residues. The fire guard shall be trained in the nature of any fire that may occur, and be proficient in the proper use of fire extinguishing equipment. Where hot work may create temperature increases in a wall, bulkhead, or other separating structure, an additional fire guard shall be posted on the side opposite the work site. A system of communication shall be established to permit the fire guard to convey the development of hazardous conditions on the opposite side of separating structures, and to signal the necessity to stop work. Air Force shall refer to AFOSH 127–56.

CAUTION

Vaporizing liquid fire extinguishers such as CO_2 shall not be used in confined or enclosed spaces.

NOTE

Exceptions may be made in selection of fire extinguishing equipment where restrictions exist due to the nature of the space.

2.3.1.8 FIRE EXTINGUISHING EQUIPMENT. Air Force shall use fire extinguishing equipment as prescribed by the local Fire Department. Suitable fire extinguishing equipment shall be provided based on the nature and extent of the flammables or combustibles present and the type of fire that may occur. Water extinguishers or water hoses equipped with fog nozzles or applicators are most suitable for hot work in the presence of ordinary class A, combustible material or flammable residues or coatings. Fire extinguishing equipment shall be selected based on the following:

a. Ability of extinguishing agents to suppress the fire.

b. Any hazard that may be created by the discharge of the agent into the space.

c. The capacity of the equipment in relationship to the size and intensity potential fires.

Table 2–3. Required Exhaust Ventilation

Class I Space
A space that contains atmospheres or conditions that are or may reasonably be expected to become Immediately Dangerous to Life or Health (IDLH). Such conditions include the presence of: 1. Flammable vapors at a concentration of 10% or greater of the lower flammable/explosion limit. 2. Oxygen content less than 16% or greater than 22%. 3. Presence of toxics which exceed a level from which a person could escape within 30 minutes without impairing symptoms or irreversible health effects. 4. Any combination of these conditions.
Class II Space
A confined or enclosed space containing atmosphere or conditions that are or may reasonably be expected to become dangerous, but are not immediately life threatening. Such conditions include the presence of: l. Flammables. 2. Flammable atmosphere in concentrations at or greater than 1% but less than 10% of the lower flammable/explosive limit. 3. Oxygen levels greater than 16% but less than 20% or greater than 21% but less than 22%. 4. Toxics at concentrations below levels that are IDLH but at or above established permissible exposure limits. 5. Any combination of such conditions.
Class III Space
A confined or enclosed space containing atmospheres or conditions that are or may reasonably be expected to become contaminated, but not to a level that is dangerous or immediately life threatening. Such conditions include the presence of: l. Flammables. 2. Flammable atmospheres in concentrations less than 1% of the Lower Explosive Limit (LEL). 3. Oxygen levels consistent with outside ambient conditions (20% or 21%). 4. Toxics at concentrations below Permissible Exposure Limits (PEL). 5. Prescribed conditions for flammables, oxygen, and toxics can be reliably and consistently maintained. 6. Any combination of such conditions.
Class IV Space
A space that contains no flammables or toxics, has an oxygen level between 20% to 21%, and presents little potential for generation of hazardous conditions as described above.

2.4 SAFETY FOR ”ON AIRCRAFT” WELDING/ BRAZING ABOARD SHIP.

NOTE

Welding aboard ships on aircraft should be done only in cases where parts cannot be removed to a welding area. All safety practices in this manual must be followed and authority to weld shall be sole responsibility of the Commanding Officer.

2.4.1 HOT WORK IN THE PRESENCE OF FLAMMABLE COATINGS. Air Force shall refer to AFOSH 91–5. The flammability of coatings shall be determined prior to starting hot work. If flammability of coating is unknown, tests shall be conducted to determine flammability, or worst case conditions must be assumed to exist. Coatings known or found by testing to be combustible shall be removed from the location of the hot work, to a distance sufficient to prevent ignition or outgassing from temperature increase of coating materials in the unstripped areas. The distance required for stripping of coating material will vary according to the material involved and the nature of the hot work, but in no case shall be less than 4 inches on all sides from the outermost limits of the hot work. To conduct hot work, proceed as follows:

NOTE

Suitable fire extinguishing equipment shall be immediately available, charged and ready for instant use.

a. Periodic or continuous testing shall be conducted from start of hot work to ensure flammable atmospheres are not being produced.

b. Where significant outgassing is detected, hot work shall be stopped and further stripping conducted, artificial cooling methods employed, or other means applied to prevent temperature increases in the unstripped areas.

c. Flame or uncontrolled heat shall not be used for stripping flammable coatings.

d. Methods shall be employed to prevent hot slag or sparks from falling onto flammable coatings in the area of the hot work.

e. The wetting down of surrounding areas to reduce ignition potential may also be used to minimize ignition, consistent with the nature of the coating operation.

2.4.1.1 SOFT, GREASY PRESERVATIVE COATINGS. Soft, greasy coatings may present hazards more serious than those presented by hard surface coatings. Some soft coatings may have much lower flash points, produce outgassing at lower temperatures, and may ignite more easily from hot slag or sparks. Some materials may, under certain conditions, ”surface flash,” which would involve the entire coated area. The above problems are often further complicated by difficulty in walking, standing, and maneuvering on slippery surfaces, increasing the possibility of falls, dropping lighted torches on unstripped material, etc. Therefore, accomplish the following prior to start of hot work in a confined or enclosed space coated with soft, greasy preservatives:

a. Strip, clean, or otherwise remove the preservative from the area of the hot work a distance sufficient to prevent outgassing and to prevent ignition from heat, sparks, slag, etc.

b. The space shall be tested and certified ”SAFE For Hot Work” by the activity GFE or hot work certified AVGFET.

NOTE

Valves to pipes, tubes, and similar items shall be closed and the pipes blanked off, where possible, to prevent inadvertent discharge or backflow of materials into the space.

2.4.1.2 HOT WORK ON PIPES, TUBES OR COILS. Pipes, tubes, coils, or similar items which service or enter and exit a confined or enclosed space shall be flushed, blown, purged, or otherwise cleaned and certified ”SAFE For Hot Work” prior to the start of hot work. Where they are not cleaned and certified, they shall be prominently tagged ”NOT Safe For Hot Work”. The Navy Gas Free Certificate for the space shall also contain a notation to that effect.

2.4.1.3 HOT WORK IN THE PRESENCE OF PRESSURIZED SYSTEMS. Prior to start of hot work in areas that contain pressurized systems (such as fuel, hydraulic, liquid oxygen etc.), the systems shall be depressurized if there is a possibility that these systems could be affected by the hot work. Piping, fittings, valves, and other system components shall be protected from damage resulting from contact with flames, arcs, hot slag, or sparks. Care shall be taken to ensure that all contamination within the space, such as leaking hydraulic fluid, is cleaned and removed prior to start of hot work. Hydraulic fluid in the presence of high temperatures can decompose and produce highly toxic byproducts.

2.4.1.4 COMPRESSED GAS CYLINDERS. Compressed gas cylinders shall be transported, handled, and stored in accordance with service standards. Compressed gas cylinders or gas manifolds used in welding and cutting operations shall not be taken into a confined or enclosed space. Compressed gas cylinders or gas manifolds shall be placed outside the space, in open air, in an area not subject to any fire, explosion, or emergency that may occur within the space.

2.4.1.5 GAS WELDING AND CUTTING EQUIPMENT. Gas welding and cutting equipment such as hoses, connections, torches, etc., shall be inspected, tested, operated, and maintained in accordance with current service standards.

2.4.1.6 GAS SUPPLIES. Gas supplies shall be turned off at the cylinder or manifold outside the space when equipment is unattended or unused for substantial periods of time, such as breaks or lunch periods. Turn off gas supplies and remove torches and hoses from the space during shift changes or if the equipment is to be idle overnight. Open–ended hoses shall be immediately removed from the space when torches or other devices are removed from the hose.

2.4.1.7 ELECTRIC ARC MACHINES. Electric arc machines shall not be taken into a confined or enclosed space. Electric arc equipment shall be inspected, tested, operated, and maintained in accordance with current service standards.

2.4.1.8 ELECTRODE HOLDERS. When electrode holders are to be left unattended or unused for substantial periods of time such as breaks or lunch periods, the electrodes shall be removed from the holders. The holders shall be placed in a safe location and protected, and the power switch to the equipment shall be turned off. If unattended for extended periods or the equipment is to be idle overnight, electrode holders, cables, and other equipment shall be removed from the space and the power supply to the equipment disconnected.

2.4.1.9 ON–AIRCRAFT WELDING. Obtain Hot Work permit in accordance with service instructions or program manuals. Air Force shall refer to AFOSH 91–5.

WARNING

Do not perform hot work without specific authorization of activity Gas Free Engineer (GFE) or hot work certified Aviation Gas Free Engineering Technician (AVGFET).

2.4.1.10 HAZARDOUS BY–PRODUCTS. Welding, cutting or burning in the presence of certain materials (such as hydraulic fluids), or the application of heat to such materials can result in the decomposition of the materials and the production of hazardous byproducts. Procedures shall be established to ensure that hot work is not conducted on or in the vicinity of such materials. Welding or cutting operations which produce high levels of ultra–violet radiation shall not be conducted within 200 feet of chlorinated solvents.

CAUTION

If flammable residues, liquids, or vapors are present, the object shall be made safe. Objects such as those listed above shall also be inspected to determine whether water or other nonflammable liquids are present which, when heated, would build up excessive pressure. If such liquids are determined to be present, the object should be vented, cooled, or otherwise made safe during the application of heat.

2.4.1.11 HOT WORK ON CLOSED CONTAINERS OR STRUCTURES. Drums, containers, or hollow structures that have contained flammable substances shall be treated as follows:

a. Before welding, cutting, or heating, the object should be filled with water or thoroughly cleaned of flammable substances, ventilated, and tested.

b. Before heat is applied to a drum, container, or hollow structure, a vent or opening shall be provided for the release of any pressure buildup during the application of heat.

c. Before welding, cutting, heating, or brazing is begun on structural voids, the object shall be inspected and, if necessary, tested for the presence of flammable residues, liquids, or vapors.

d. Jacketed vessels shall be vented before and during welding, cutting, or heating operations, in order to release any pressure that may build up during the application of heat.

2.4.1.12 SPECIAL FUEL SYSTEM/FUEL CELL PROCEDURES. Welding and torch brazing operations performed in or around fuel systems and fuel cells must be accomplished by thoroughly proficient operators following specific procedures.

a. Respond to supervision.

b. Are adequately trained.

c. Understand emergency evacuation procedures from fuel cells as described in NAVAIR 0l–1A–35, T.O. 1–1–3.

NOTE

Details of these procedures are found in NAVAIR 0l–1A–35, T.O. 1–1–3.

2.4.1.13 TESTING PROCEDURES FOR CONFINED/ ENCLOSED SPACES. Air Force shall refer to AFOSH 127–25 T.O. 1–1–3. Navy shall refer to NAVAIR 01–1A–35 as applicable. Prior to beginning work ensure a hot work permit or GFE certificate Is posted.

2.4.1.14 SAFETY PRECAUTIONS IN OXYACETYLENE WELDING. The following safety precautions must be observed:

a. Do not experiment with torches or regulators in any way. Do not use oxygen regulators with acetylene cylinders:

b. Always use the proper tip or nozzle, and always operate it at the proper pressure for the particular work involved. This information should be taken from work sheets or tables supplied with the equipment.

c. When not in use, make certain that the torch is not burning and that the valves are tightly closed. Do not hang the torch with its hose on the regulator or cylinder valves. If left unattended for 15 minutes or more, secure before leaving welding area.

d. Do not light a torch with a match, from hot metal, or in a confined space. The explosive mixture of acetylene and oxygen might cause personal injury or property damage when ignited. Use friction lighters, stationary pilot flames, or some other suitable source of ignition.

e. When working in confined spaces provide adequate ventilation for the dissipation of explosive gases that may be generated.

f. Keep a clear space between the cylinder and the work so that the cylinder valves can be reached easily and quickly.

g. Store full and empty cylinders separately and mark the latter MT.

h. Never use cylinders for rollers, supports, or any purpose other than that for which they are intended.

2.4.1.15 ACETYLENE CYLINDERS. Always refer to acetylene by its full name and not by the word ”gas” alone.

a. Acetylene cylinders must be handled with care to avoid damage to the valves or the safety fuse plug. The cylinders must be stored upright, well protected and in a dry location at least 20 feet from highly combustible materials such as oil, paint or flammables. If received in other than vertical position, the cylinder must be stored in the upright position at least 8 hours prior to use. Most cylinders are fitted with valve protection caps. These caps must always be in place, handtight, except when cylinders are in use or connected for use. Do not store the cylinders near radiators, furnaces, or in any above normal temperature area. In tropical climate, care must be taken not to store acetylene in areas where the temperature is in excess of l37° F (58° C). Heat will increase the pressure which may cause the safety fuse plug in the cylinder to blow out. Storage areas should be located away from elevators, gangways, or other places where there is danger of their being knocked over or damaged by falling objects.

b. A suitable truck, chain, or strap must be used to prevent cylinders from falling or being knocked over while in use. Cylinders should be kept at a safe distance from the welding operation so that there will be little possibility of sparks, hot slag, or flames reaching them. They should be kept away from radiators, piping systems, layout tables, etc., which may be used for grounding electrical circuits.

c. Never use acetylene from cylinders without reducing pressure with a suitable pressure reducing regulator and flashback attachments. Never use acetylene at pressures in excess of 15 psi.

d. Before attaching the pressure regulators, open each acetylene cylinder valve for an instant to blow dirt out of the nozzles. Wipe off the connection seat with a clean cloth. Do not stand in front of valves when opening them.

e. Outlet valves which have become clogged with ice should be thawed with warm water. Do not use scalding water or an open flame.

f. Be sure the regulator tension screw is released before opening the cylinder valve. Always open the valve slowly to avoid strain on the regulator gage which records the cylinder pressure. Do not open the valve more than one and one–half turns. Usually one–half turn is sufficient. Always use the special T–wrench provided for opening the acetylene cylinder valve. Leave this wrench on the stem of the valve while the cylinder is in use so that the acetylene can be turned off quickly in an emergency.

g. Acetylene is a highly combustible fuel gas and great care should be taken to keep sparks, flames, and heat away from the cylinders. Never open an acetylene cylinder valve near other welding or cutting work.

h. Never test for an acetylene leak with an open flame. Test all joints with leak test compound, MIL–L–25567. Should a leak occur around the valve stem of the cylinder, close the valve and tighten the packing nut. Cylinders leaking around the safety fuse plug should be taken outdoors, away from all fires and sparks, and the valve opened slightly to permit the contents to escape.

i. Never interchange acetylene regulators, hose, or other apparatus with similar equipment intended for oxygen.

j. Always turn the acetylene cylinder so that the valve outlet will point away from the oxygen cylinder.

k. When returning empty cylinders, see that the valves are closed to prevent escape of residual acetylene or acetone solvent. Screw on protecting caps.

2.5 OXYGEN CYLINDERS.

WARNING

Oil or grease in the presence of oxygen will ignite violently, especially in an enclosed pressurized area.

NOTE

Oxygen shall always be referred to by its full name.

a. Oxygen cylinders shall not be stored near highly combustible material, especially oil and grease; or near reserve stocks of acetylene or other fuel– gas cylinders, or near any other substance likely to cause or accelerate fire.

b. Oxygen cylinders in storage shall be separated from fuel–gas cylinders or combustible materials (especially oil or grease), a minimum distance of 20 feet or by a noncombustible barrier at least 5 feet high having a fire–resistance rating of at least one–half hour.

c. Where a liquid oxygen system is to be used to supply gaseous oxygen for welding or cutting and the system has a storage capacity of more than 13,000 cubic feet of oxygen (measured at 14.7 psi and 70° F (2l° C)), connected in service or ready for service, or more than 25,000 cubic feet of oxygen (measured at 14.7 psi and 70° F (2l° C), including unconnected reserves on hand at the site, it shall comply with the provisions of the Standard for Bulk Oxygen Systems at Consumer Sites, NFPA No. 566– 1965, National Fire Protection Association.

d. When oxygen cylinders are in use or being moved, care must be taken to avoid dropping, knocking over, or striking the cylinders with heavy objects. Do not handle oxygen cylinders without safety caps installed.

e. All oxygen cylinders with leaky valves or safety fuse plugs and discs should be set aside and marked for the attention of the supplier. Do not tamper with or attempt to repair oxygen cylinder valves. Do not use a hammer or wrench to open valves.

WARNING

Oxygen must not be substituted for compressed air in pneumatic tools nor used to blow out pipe lines, test radiators, purge tanks or containers, or to ”dust” clothing or work.

f. Before attaching the pressure regulators, open each oxygen cylinder valve for an instant to blow dirt out of the nozzles. Wipe off the connection seat with a clean cloth. Do not stand in front of valves when opening them.

g. The cylinder valve shall be opened slowly to prevent damage to the regulator high pressure gage mechanism. Ensure that the regulator tension screw is released before opening the valve. When not in use the cylinder valve should be closed, and the protecting caps screwed on to prevent damage to the valve.

h. When the oxygen cylinder is in use, the valve must be opened to the limit to prevent leakage around the valve stem.

i. Regulators shall always be used on oxygen cylinders to reduce the cylinder pressure to a low working pressure since the high cylinder pressure can burst the hose.

j. Oxygen regulators, hose, or other apparatus with similar equipment intended for other gases shall not be inter–changed.

2.6 HOSES.

a. Hoses must not be allowed to come in contact with oil or grease. These will penetrate and deteriorate the rubber and constitute a hazard with oxygen.

b. Precautions.

(1) Hoses must not be walked on nor run over.

(2) Kinks and tangles shall be avoided.

(3) Hoses must not be left where they can be tripped over since this could cause personal injury, damaged connections or upset cylinders.

(4) No work shall be performed with hoses over the shoulder, around the leg(s) or tied to waist.

c. Hoses shall be protected from hot slag, flying sparks, and open flames.

d. Hose connections which do not fit shall never be forced. White lead, oil, grease, or other pipe fitting compounds for connections on hose, torch, or other equipment shall not be used. Hoses shall never be crimped to shut off gases.

e. Prior to use, inspect all hoses for damage. Hoses with abrasions or cracks shall be replaced. Do not use open flames to check for leaks in acetylene hoses. Examine all hoses periodically for leaks by immersing in water while under pressure. Do not use matches to check for leaks in acetylene hose. Repair leaks by cutting hose and inserting a brass splice. Do not use tape for mending. Replace hose if necessary.

f. Make sure hoses are securely attached to torches and regulators before using.

g. Do not use new or stored hose lengths without first blowing them out to eliminate talc or accumulated foreign matter which might otherwise enter and clog the torch parts.

2.7 SAFETY PRECAUTIONS FOR ARC WELDING.

2.7.1 ELECTRIC CIRCUITS. The electric current used in welding can cause severe shock or death. The precautions listed below should always be observed:

a. Check the welding equipment to make certain that electrode connections and insulation on holders and cables are in good condition.

b. Keep hands and body insulated from both the work and the metal electrode holder. Avoid standing on wet floors.

c. Perform all welding operations within the rated capacity of the welding cables. Excessive heating will impair the insulation and damage the cable leads.

d. Inspect the cables periodically for looseness at the joints, defects due to wear, or other damage. Defective or loose cables are a fire hazard. Defective electrode holders should be replaced and connections to the holder should be tightened.

e. Welding generators should be located or shielded so that dust, water, or other foreign matter will not enter the electrical windings or the bearings.

f. The presence of moisture (fog, rain, sweat) increase the risk of shock.

2.8 WELDING MACHINES.

a. When electric generators powered by internal combustion engines are used inside buildings or in confined areas the engine exhaust must be conducted to the outside atmosphere.

(1) Welding generating equipment shall be placarded as follows: “Warning – Keep 5 ft (1.5 m) (Horizontally) Clear of Aircraft Engines, Fuel Tank Areas and Vents”. (Not applicable to Air Force).

NOTE

The compressed gas cylinder shall be securely fastened to prevent tipping, and the regulator and gage shall be in proper working condition.

b. All welding equipment must be checked to ensure that the electrode connections and the insulation on holders and cables are in good condition. All checking should be done on dead circuits. All serious trouble should be investigated by a trained electrician.

c. A motor–generator type of welding machine must have a power ground on the machine because stray current may cause a severe shock to the operator if he should contact the machine and a good ground.

d. The polarity switch should not be operated while the machine is operating under welding current load. Consequent arcing at the switch will damage the contact surfaces, and the flash may burn the person operating the switch.

e. The rotary switch should not be operated for current settings while the machine is operating under the welding current load; severe burning of the switch contact surface will result. Operate the rotary switch while the machine is idling.

f. The power source must be turned off when leaving welding machine unattended.

g. Well insulated electrode holders and cables shall be used. Dry protective covering on hands and body shall be worn.

h. Partially used electrodes shall be removed from the holders when not in use and a place provided to hang up or lay down the holder where it will not come in contact with persons or conducting objects.

i. The work clamp must be securely attached to the work before the welding operation is started.

2.9 PROTECTIVE SCREENS.

a. When welding is done near other personnel, screens should be used to protect the eyes from the arc or reflected glare. See paragraph 2.2.9c. for screen design and method of use.

b. In addition to using portable screens to protect other personnel, screens should be used, when necessary, to prevent drafts of air from interfering with the stability of the arc.

2.10 SAFETY PRECAUTIONS FOR GAS SHIELDED ARC WELDING.

2.10.1 POTENTIAL HAZARDS AND PROTECTIVE MEASURES. Gas shielded arc welding processes have certain dangers associated with them. The hazards which are peculiar to or might be increased by gas shielded arc welding are gases, radiant energy, and metal fumes.

2.11 PROTECTIVE MEASURES FOR GASES.

a. Gases.

(1) Ozone. Ozone concentration increases with the type of electrodes used, amperage, extension of arc time, and increased shielding gas flow. If welding is carried out in confined spaces and poorly ventilated areas the ozone concentration may increase to harmful levels. The exposure level to ozone will be reduced by adherence of good welding practices and utilizing properly designed ventilation systems.

(2) Nitrogen Oxides. Natural ventilation may be sufficient to reduce the hazard of exposure to nitrogen oxides during welding operations provided all three ventilation criteria given in paragraph 2.2.10.3 are satisfied. Nitrogen oxide concentrations will be very high when performing gas tungsten–arc cutting of stainless steel, using a 90 percent nitrogen – 10 percent argon mixture. In addition, high concentrations have been found during experimental use of nitrogen as a shield gas. Good industrial hygiene practices dictate that mechanical ventilation, as defined in paragraph 2.2.10.5, be used during welding or cutting of metals.

(3) Carbon Dioxide and Carbon Monoxide. Carbon dioxide is dissociated by the heat of the arc to form carbon monoxide. The hazard from inhalation of these gases will be minimal provided ventilation requirements as prescribed in paragraph 2.2.10.3 are satisfied. However, where the welding fumes pass through the welder's breathing zone or where welding is performed in confined space, ventilation requirements as prescribed in paragraph 2.2.10.5 shall be adhered to.

(4) Vapors of Chlorinated Solvents. Ultraviolet radiation from the welding or cutting arc can decompose the vapors of chlorinated hydrocarbons, to form highly toxic substances. Eye, nose and throat irritation can result when the welder is exposed to these substances. Sources of the vapors can be wiping rags, vapor degreasers or open containers of the solvent. Since this decomposition can occur even at a considerable distance from the arc, the sources of the chlorinated solvents should be located so that no solvent vapor will reach the welding or cutting area.

b. Radiant Energy. Electric arcs as well as gas flames produce ultraviolet and infrared rays which have a harmful effect on the eyes and skin under continued or repeated exposure. The usual effect of ultraviolet is to "sun–burn" the surface of the eye, which is painful and disabling but generally temporary. Ultraviolet radiation may also produce the same effects on the skin as a severe sunburn. Production of ultra–

violet radiation, hence the intensity, doubles when gas–shielded arc welding is performed instead of shielded metal arc. Infrared radiations have the effect of heating the tissue with which it comes in contact. If the heat is not sufficient to cause an ordinary thermal burn, the exposure is minimal.

c. Metal Fumes. The physiological response from exposure to metal fumes will vary depending upon the metal being welded. Ventilation and personal protective equipment requirements as prescribed in paragraph 2.2.10.3 shall be employed to prevent hazardous exposure.

2.12 SAFETY PRECAUTIONS FOR WELDING AND CUTTING POLYURETHANE FOAM FILLED ASSEMBLIES.

2.12.1 Welding or cutting parts filled with polyurethane foam shall be accomplished only after all appropriate safety measures have been complied with.

2.13 FIRE PROTECTION. AIR FORCE SHALL REFER TO AFOSH 127–56.

a. Aircraft hangars in which welding is performed shall be equipped with the fixed fire protection equipment specified in Chapters 12 and 13 of NFPA 409, Standard on Aircraft Hangars. No welding shall be permitted if such fixed fire protection equipment is inoperative for any reason. Hangars are equipped with automatic fire detection systems. This must be taken into consideration, especially with regard to type of system where welding is to be performed. Care must be taken to avoid the causing of false alarms or accidental actuation.

b. The specific location where the welding is being done shall be roped off or otherwise segregated by physical barriers to prevent unintended entry into the welding area. Placards reading "Welding Operations in Progress" shall be prominently displayed.

c. Screens shall be placed around the welding operation.

d. Good housekeeping shall prevail in the welding area. Floor drains in the area of a welding operation shall be checked periodically to determine that no flammable or combustible liquids or vapors are present.

e. A fire extinguisher having a minimum rating of 20 B (minimum capacity 15 lb (6.8 kg) of agent) shall be positioned in the immediate area of the welding operation ready for instant use. As a backup for the portable extinguisher, a wheeled extinguisher having a minimum rating of 80 B (minimum capacity 125 lb (58 kg) of agent) shall be readily available. A qualified fire watcher (see NFPA 5lB, Standard for Fire Prevention in Use of Cutting and Welding Processes, for training of fire watcher) shall be assigned to operate this equipment and shall monitor the entire welding operation. In the event a hazardous condition develops, he shall have the authority to stop the welding operation.

2.14 FIRE WATCHER ASSIGNMENT.

a. Fire watchers shall be assigned by the individual responsible for authorizing cutting and welding whenever it is performed in locations where other than a minor fire might develop, or any of the following conditions exist:

(1) Appreciable combustible material in building construction or contents is closer than 35 ft. (11 m) to the point of operation.

(2) Appreciable combustibles are more than 35 ft. (11 m) away but are easily ignited by sparks.

(3) Wall or floor openings within a 35 ft. (11 m) radius exposing combustible material in adjacent areas including concealed spaces in walls or floors.

(4) Combustible materials are adjacent to the opposite side of metal partitions, walls, ceilings or roofs and are likely to be ignited by conduction or radiation.

2.15 FIRE WATCHER RESPONSIBILITIES.

a. Fire watchers shall have fire extinguishing equipment readily available and be trained in its use, including practice on test fires.

b. Fire watchers shall be familiar with facilities and procedures for sounding an alarm in the event of a fire.

c. Fire watchers shall watch for fires in all exposed areas, and try to extinguish them first only when obviously within the capacity of the equipment available, or otherwise sound the alarm immediately.

d. A fire watch shall be maintained for at least a half hour after completion of cutting or welding operations to detect and extinguish smoldering fires.

2.16 BASIC PRECAUTIONS OUTLINED HEREIN SHOULD APPLY TO THE FOLLOWING OPERATIONS:

a. Stress relieving of certain portions of the aircraft engines or structures by normalizing through the use of an oxyacetylene flame.

b. Silver soldering when required on certain electrical connections and fluid lines.

2.17 SAFETY FOR ON–SUPPORT EQUIPMENT WELDING, CUTTING, AND BRAZING.

a. Support equipment operations performed in hangars/outdoors shall conform to the requirements of this manual.

SECTION III.
QUALIFICATION CERTIFICATION REQUIREMENTS
INTRODUCTION

3.1 SCOPE.

This section gives the DOD methods and procedures required for certification of military aircraft and aircraft support equipment, missile welders, and missile system real property and installed equipment. It does not apply to civil engineering, motor vehicle maintenance or other support activities. This section gives methods and procedures for primarily the Gas Tungsten Arc Welding (GTAW) process. Gas Metal Arc Welding (GMAW), Shielded Metal Arc Welding (SMAW) and Oxyfuel Brazing (OFB) are required for repair of aircraft support equipment and are included in this certification section. If methods and procedures for other welding certifications are required they may be obtained by following the instructions given in paragraph 3.7.

3.2 GENERAL.

DOD aviation welders may be required to certify in the following processes:

a. Gas Tungsten Arc Welding (GTAW).

b. Gas Metal Arc Welding (GMAW).

c. Shielded Metal Arc Welding (SMAW).

d. Oxyfuel Brazing (OFB).

To become qualified as a welder or torch brazer, an individual must be trained, tested and certified under this section and MIL–STD–1595 (GTAW, SMAW and GMAW) and/or MIL–STD–248 (oxygen–fuel torch brazing), as applicable. Refer to paragraph 3.16 for Air Force unique requirements. Refer to paragraph 3.17 for Navy unique requirements. Refer to paragraph 3.18 for Army unique requirements.

3.2.1 Certification. Paragraphs 3.1 through 3.23 of this manual describe the general requirements, welding procedures, and range of qualifications obtained for ferrous and nonferrous alloys commonly used on aircraft and missile weapon systems and support equipment.

NOTE

Refer to paragraphs 3.16, 3.17 and 3.18 for service peculiar requirements.

3.2.2 Evaluation. Paragraphs 3.22 through 3.23 of this section describe visual and radiographic tests required to examine completed test welds. Acceptance and rejection criteria are included.

3.3 PURPOSE.

This section develops standard methods and procedures to certify military aircraft and missile welders. This section conforms to the requirements of MIL–STD–1595. The procedures contained in this manual will provide welders with the qualification necessary to weld metals which must endure the extreme environments to which modern weapon systems are subjected.

3.4 RESPONSIBILITIES.

The individual service will determine the metal groups to which welders will be certified. Each service is responsible to ensure that only personnel fully trained and certified in accordance with this section are permitted to perform welding on aircraft, missile, weapon systems and support equipment. Activities that test and evaluate test welds in accordance with this technical manual may do so. Personnel evaluating test welds need not be a qualified welder. Units that are unable to perform the required test may send either the welder or the completed test welds to their geographic Air Logistics Centers (refer to T.O. 00–25–107), Naval Aviation Welding Certification Center or Army Aviation Welding Certification Center. Major commands and units are responsible for funding the certification of welders.

3.4.1 Physical Requirements. Each activity shall establish reasonable and appropriate physical requirements for welders and welding operators. It will be accepted that those whose corrected vision in each eye for long distance is better than 20/30 and for 16 inches distance permits reading of Jaeger No. 2 type will ordinarily satisfy vision needs for welding. An annual physical examination may be required to permit early detection of possible detrimental effects resulting from chronic exposures. Local medical authorities and the Industrial Hygienist shall set frequency of specific tests based on exposure data.

3.5 WELDING POSITION REQUIREMENTS.

A welder or welding operator shall be certified in accordance with MIL–STD–1595 (or equivalent AWS industrial specification) to position 6G for every metal group that will be required for his/her job function. Position 6G is the only position whereby all other positions are automatically certified. This means that a successfully certified welder to position 6G can weld sheet or tubing in any position (i.e. flat, horizontal, vertical, overhead), in the thickness range from 0.025 to 0.100 inch. Other thicknesses and positions must be certified to specific welding procedure specifications (WPS). Refer to Table 3–1 and Figure 3–1 for clarification. Field activity welders are frequently required to weld in an overhead and vertical position even through they are not certified to do so. Certifying in the 6G position will produce the most competent welders at the least cost to the commands. This certification requirement applies to GTAW processes only.

The GMAW and SMAW processes are used by support equipment welders that are not required to be certified in all positions. Positions 1G and 2F are the minimum required for GMAW and SMAW certifications. Refer to Figure 3–1 for clarification.

3.6 CERTIFICATION REQUIREMENTS FOR MILITARY AND CIVILIAN WELDERS AT THE INTERMEDIATE LEVEL.

To maintain certification, all Army/Navy military and civilian welders at the Intermediate level must weld at least once every 3 months in any given welding process. This does not apply to depot level welders.

NOTE

> Navy/Army/Civilian welders or welding operators at the Intermediate level shall be requalified every three years to the same requirements as an original qualification. Civilian welders at depot activities shall be requalified every 5 years.

3.7 WELDER CERTIFICATION PROCEDURES NOT CONTAINED IN THIS SECTION.

Most welding conditions that will be experienced by military aircraft, missile welders and support equipment are covered by this section. For welding operations that are not contained herein, contact your local support depot.

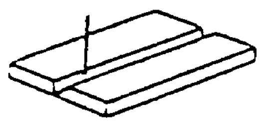
3.8 CERTIFICATION PROCEDURES.

NOTE

> If there are any conflicts between MIL–STD–1595 and this manual, this manual will take precedence.

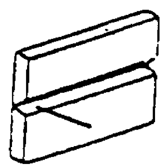
a. Qualified welders shall be certified for each metal group listed in Table 3–2 of this section, in which they are to perform welding and/or torch brazing.

b. Test specimen materials for certification/recertification shall be prepared and furnished by the organization responsible for observing the welding certification process. The welder identified on the specimen shall weld the specimen in the welder’s normal duty shop. The shop supervisor or maintenance officer, shall assure that each specimen is welded by the welder identified on the specimen, and returned to the welding instructor at one of the examination facilities listed in paragraphs 3.16, 3.17 and 3.18 for service specific requirements.



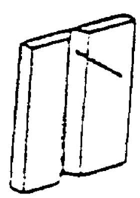
1G

Flat position. The welding position used to weld from the upper side of the joint; the face of the weld is approximately horizontal.



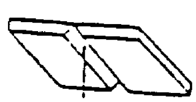
2G

Horizontal position. The position of welding in which the axis of the weld lies in an approximately horizontal plane and the face of the weld lies in an approximately vertical plane.



3G

Vertical position. The position of welding in which the axis of the weld is approximately vertical.



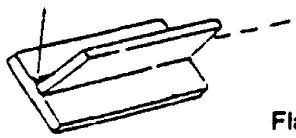
4G

Overhead position. The position in which welding is performed from the underside of the joint.

Groove weld in sheet: positions 1G, 2G, 3G and 4G.

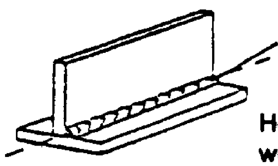
Figure 3-1. Weld Positions (from Table 3-1) (Sheet 1 of 4)

1F



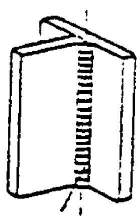
Flat position. The welding position used to weld from the upper side of the joint; the face of the weld is approximately horizontal.

2F



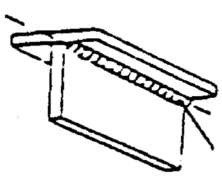
Horizontal position. The position in which welding is performed on the upper side of an approximately horizontal surface and against an approximately vertical surface.

3F



Vertical position. The position of welding in which the axis of the weld is approximately vertical.

4F

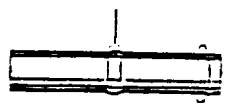


Overhead position. The position in which welding is performed from the underside of the joint.

Fillet weld in sheet: positions 1F, 2F, 3F and 4F.

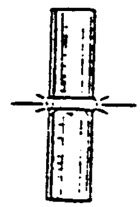
Figure 3–1. Weld Positions (from Table 3–1) (Sheet 2)

Horizontal rolled position. The position of a pipe joint in which the axis of the pipe is approximately horizontal, and welding is performed in the flat position by rotating the pipe.



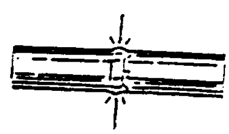
1G

Vertical position. The position of a pipe joint in which welding is performed in the horizontal position and the pipe is not rotated during welding.



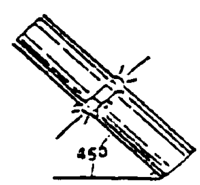
2G

Horizontal fixed position. The position of a pipe joint in which the axis of the pipe is approximately horizontal and the pipe is not rotated during welding.



5G

Inclined position. The position of a pipe joint in which the axis of the pipe is approximately at an angle of 45° to the horizontal and the pipe is not rotated during welding.

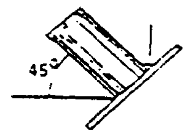


6G

Groove weld in tube: positions 1G, 2G, 5G and 6G.

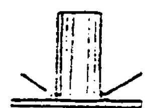
Figure 3–1. Weld Positions (from Table 3–1) (Sheet 3)

Flat position. The welding position used to weld from the upper side of the joint; the face of the weld is approximately horizontal and the pipe is rotated during welding.



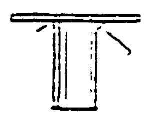
1F

Horizontal position. The position In which welding is performed on the upper side of an approximately horizontal surface and against an approximately vertical surface and the pipe is not rotated during welding.



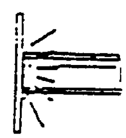
2F

Overhead position. The position in which welding is performed from the underside of the joint and the pipe is not rotated during welding.



4F

Multiple position. The position in which the axis of the pipe is approximately horizontal and the pipe is not rotated during welding.



5F

Fillet weld in tube: positions 1F, 2F, 4F and 5F.

Figure 3–1. Weld Positions (from Table 3–1) (Sheet 4)

NOTE

Test specimens shall be a maximum length of 8 inches and a minimum length of 4 inches. Test specimens for GMAW and SMAW shall be 6 inches long and a combined width of 4 inches in the as welded condition. Refer to paragraph 3.16 for unique Air Force requirements.

c. Welders whose specimens fail to meet minimum requirements shall have one additional requalification examination. Refer to Figure 3–2 for sequence chart. The recertification examination requires a double set of specimens and recording documents identified as recertification examination. Should the results of either specimen of a recertification examination be unsatisfactory, the operator shall require further training. Welders who fail the recertification examination will not perform any production welding operations until recertification is achieved.

d. Weld specimens that are visually satisfactory to the welding instructor/shop supervisor or maintenance officer shall be forwarded together with the Welding Examination Record (Figure 3–3), to the appropriate welding examination and evaluation facility for final examination/test. See paragraphs 3.16, 3.17 and 3.18 for location of evaluation facilities.

e. Each Welding Examination Record (see Figure 3–3) indicating acceptable weld specimens, assigned by evaluating lab and the welding inspector/instructor, shall be forwarded to the service training coordinator for processing and issuing of Welding Certification Card (see Figure 3–4).

f. The certifying facility shall maintain records of training, certification/recertification of all qualified welders for the duration of their use for a period not less than two years.

3.9 FAILURE TO MEET CERTIFICATION REQUIREMENTS.

A welder who fails to meet the certification requirements for one or more of the required test welds contained in this section may be retested as described in paragraph 3.8.c.

Table 3–1. Welding Position, Base Metal Form, and Weld Type Qualified by Test Weld (per MIL–STD–1595)

			QUALIFIED POSITION															
TEST WELD		POSITION	SHEET								TUBE							
FORM	WELD TYPE		Groove				Fillet [1]				Groove				Fillet [1]			
			1G	2G	3G	4G	1F	2F	3F	4F	1G	2G	5G	6G	1F	2F	4F	5F
Sheet to sheet	Groove	1G	X				X	X			X				X			
		2G	X				X	X			X	X			X			
		3G	X		X		X	X	X		X				X			
		4G	X		X		X	X		X	X				X			
Sheet to sheet	Fillet	1F					X								X			
		2G					X	X							X	X		
		3F					X	X	X						X			
		4F					X	X		X					X	X	X	
Tube to tube	Groove	1G	X				X	X			X				X	X		
		2G	X	X			X	X			X	X			X	X		
		5G	X		X	X	X		X	X	X		X		X		X	X
		6G	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tube to sheet	Fillet	1F					X								X			
		2F					X	X							X	X		
		4F					X	X		X					X	X	X	
		5F					X	X	X	X					X	X	X	X

[1] A groove test weld does not qualify for fillet welds in base metal equal to or less than 0.063 inch in thickness.

3.10 RECERTIFICATION.

A welder shall be recertified to the same requirements as an original certification. It shall be the responsibility of the service commands to determine the interval of recertification. It is recommended that intermittent or part time welders recertify more frequently than full time welders. Recertification is required when:

a. A welder has not welded with a given welding process for a period of 90 days; except that this period shall be extended to 180 days if the welder has welded with another welding process (i.e. GMAW, SMAW, etc.).

b. There is specific reason to question the ability of a welder or welding operator to meet the requirements for certification in a given welding process. Specific reasons may include poor quality welds, eyesight acuity, health and behavior.

c. The welder fails retesting as described in paragraph 3.8.c.

3.11 DEFINITIONS.

The welding terms used in this manual shall be interpreted in accordance with Terms and Definitions, AWS A3.0, published by the American Welding Society. Some of these terms are defined in the Glossary of Terms in this manual. For further definitions and illustrations refer to AWS A3.0.

3.12 DETAILED CERTIFICATION REQUIREMENTS.

3.12.1 Welding Process. For welders and welding operators, a test weld made with a given welding process as listed in paragraph 3.2 is qualified only to that welding process. These procedures do not apply to welding processes not included in that list.

3.12.1.1 Certification in GTAW, GMAW, SMAW and OFB shall be in accordance with the following paragraphs:

a. Certification in GTAW and GMAW shall be the successful welding of the joints described in WPS #1 through #7 and #11 through #26 for GTAW and #8 for GMAW of Table 3–3. Visual and radiographic evaluation of the test weldment shall be in accordance with paragraphs 3.22 and 3.23 of this section.

NOTE

> The individual service will determine the metal groups to which the welders will be certified.

b. Certification in SMAW shall be the successful welding of the joint described in WPS #10 of Table 3–3. Visual and radiographic evaluation of the test weldment shall be in accordance with paragraphs 3.22 and 3.23 of this section.

c. Certification tests in OFB (see WPS #9) are intended to determine the ability of brazers and brazing operators to make sound joints. Renewal of certification of a performance specification is required for brazers when:

(1) Three or five years has passed from the date of last certification or recertification. Refer to paragraph 3.2 for specific service recertification intervals.

(2) A brazer has not used the brazing process for a period of 6 months or more.

(3) When there is a specific reason to question the ability to make brazes that meet this specification.

3.12.2 Record of Tests. The training department/shop supervisor shall maintain a record of the procedures, including the essential variables under which brazers and brazing operators are examined and the results of the examinations.

3.12.3 Type and Number of Test Specimens. The type and number of test specimens that must be tested to qualify a performance certification are given in Figure 3–5. Tests for brazers shall meet the requirements of paragraph 3.12.4 and figures 3–5 and 3–6.

3.12.4 Brazers. Each brazer who is qualified to braze under the rules of this specification shall pass the tests prescribed in paragraph 3.12.5 for performance certification.

Table 3-2. Base Metals

GROUP	NOMINAL DESCRIPTION	ALLOY	WPS NO.
I	Carbon and Low Alloy Steel	1010-1020	8, 10
I	Alloy Steels	4130	1, 11-13
II	Stainless Steels	321, 347	2, 14, 15
III	Precipitation Hardening Nickel-Base Alloys	INCO 718	3, 16, 17
IV	Aluminum Base Alloys	6061-T6	4, 18-20
V	Magnesium-Base Alloys	AZ92, AZ31B	5, 22, 23
VI	Titanium-Base Alloys	Ti6AL4V, Ti3Al2.5V	6, 24, 25
VII	Cobalt-Base Alloys	L605	7, 26

3.12.5 Specimens for Torch Braze. The dimensions and preparation of the workmanship sample specimen shall conform to the requirements of Figures 3-5 and 3-6. The representative joint shall be sectioned as required in Figure 3-5, sheet 1. After smoothing of the cut sides, each specimen shall be etched with a suitable etchant to give clear definition of the braze. When examined with a minimum of 4 power magnifying glass, the total voids, inclusions or unbrazed areas shall not exceed 20% of the length of the overlap.

3.12.6 Acceptance Criteria. In order to pass the peel test, the specimens shall show evidence of brazing filler metal along each edge of the joint. Specimens shall be separated or peeled by clamping across the major diameter. The separated faying surfaces of joints shall meet the following criteria:

a. The total area of defects (unbrazed areas, flux inclusions, etc.) shall not exceed 20% of the total area of any individual faying surface.

b. The sum of the lengths of the defects measured on any one line in the direction of the lap shall not exceed 25% of the lap.

c. No defect shall extend continuously from one surface of the joint to the other surface, irrespective of the direction of the defect.

3.13 BASE METALS, CERTIFICATION AND JOINT WELDING PROCEDURES.

3.13.1 General. This section describes the welding requirements and welding procedures. The conditions given in the welding procedures are of two types, nonessential and essential. Nonessential conditions may be changed as desired; provided that good welding practice is followed. Essential conditions may not be changed or may be changed only within specified limits. The status of each welding condition of the welding procedure specification is given below.

3.13.1.1 Welding Process. No change permitted. Essential.

3.13.1.2 Base Metal Composition. The base metals specified in paragraph 3.14 of this section should be used. Base metal substitutions may be made in accordance with AWS B2.1. If substitutions are made Welding Procedure Specifications (WPS) and weld test procedures must be developed from AWS B2.1. Essential.

3.13.1.3 Base Metal Thickness. No change permitted. Essential.

3.13.1.4 Tube Diameter and Wall Thickness. No change permitted. Essential.

3.13.1.5 Other Base Metal Dimensions. Larger dimensions may be substituted. Greater lengths and widths may be substituted. Nonessential.

Table 3-3. Welding Procedure Specifications

	WPS No. 1	WPS No. 2	WPS No. 3	WPS No. 4	WPS No. 5	WPS No. 6	WPS No. 7	WPS No. 8	WPS No. 9
Welding Process	GTAW	GTAW	GTAW	GTAW	GTAW	GTAW	GTAW	GMAW	Braze
Base Metal	Low alloy steel 4130	Stainless steel 347	Nickel alloy INCO 718	Aluminum alloy 6061-T6	Magnesium alloy AZ31B	Titanium 3AL2.5V	Cobalt alloy L605	Mild steel 1010-1020	SS-S-Brass
Thickness	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.250 sheet	See fig 3-5 & 3-6
Joint Description	Butt joint in tube	Butt joint in tube	Butt joint in tube	Butt joint in tube	Butt joint in tube	Butt joint in tube	Butt joint in tube	Butt joint in sheet	See fig 3-5 & 3-6
Weld Type	Single square groove - one pass	Single square groove - one pass	Single square groove - one pass	Single square groove - one pass	Single square groove - one pass	Single square groove - one pass	Single square groove - one pass	Single V groove - multiple passes	Lap
Joint Clearance	None	None	None	None	None	None	None	None	None
Backing	None	None	None	None	None	None	None	None	None
Weld Position	6G 45° tube	6G 45° tube	6G 45° tube	6G 45° tube	6G 45° tube	6G 45° tube	6G 45° tube	1G (Flat)	Vertical
Weld Progression	Forehand	Forehand	Forehand	Forehand	Forehand	Forehand	Forehand	Forehand	N/A
Filler Metal	4130	347	INCO 718	5356	AWS ERAZ92A, AMS 4395	AWS ER Ti 3AL 2.5V AMS	AMS 5796	E70S-6	AMS 2664
Diameter	0.045	0.045	0.045	0.063	0.063	0.045	0.045	0.035	0.035
Shielding Gas	Argon/10 CFH	Argon/10 CFH	Argon/10 CFH	Argon/10 CFH	Argon/10 CFH	Argon/10 CFH	Argon/10 CFH	CO2/30 psi	N/A
Nozzle Size	#7	#7	#7	#7	#7	#7	3/4	N/A	N/A
Root Shielding Gas	Argon/20 CFH	Argon/20 CFH	Argon/20 CFH	Argon/20 CFH	Argon/20 CFH	Argon/20 CFH	Argon/20 CFH	None	N/A
Current	DCEN/0-46 amps	DCEN/0-35 amps	DCEN/0-39 amps	A/C 0-40 amps	A/C 0-38 amps	DCEN/0-38 amps	DCEN/0-38 amps	DCEN/26V	N/A
Electrode/ Size	AWS EWTh2/ EWCe-2/ EWLa-1, 0.063	AWS EWTh2/ EWCe-2/ EWLa-1, 0.063	AWS EWTh2/ EWCe-2/ EWLa-1, 0.063	AWS EWTh2/ EWCe-2/ EWLa-1, 0.063	AWS EWTh2/ EWCe-2/ EWLa-1, 0.063	AWS EWTh2/ EWCe-2/ EWLa-1, 0.063	AWS EWTh2/ EWCe-2/ EWLa-1, 0.063	0.035	N/A
Remarks	See Note #1 and #3	See Note #1 and #3	See Note #1 and #3	See Note #1 and #3	See Note #1 and #3	See Note #1 and #3	See Note #1 and #3	See Note #2 and #3	See Note #1 and #3

Note 1: Incline position. The position of a tube joint in which the axis of the tube is approximately at an angle of 45° to the horizontal, and the tube is not rotated during welding.

Note 2: Joint prepared by machining edges, grinding and degreasing

Note 3: Postweld heat treatment not required

Table 3-3. Welding Procedure Specifications (Cont.)

	WPS No. 10	WPS No. 11	WPS No. 12	WPS No. 13	WPS No. 14	WPS No. 15	WPS No. 16	WPS No. 17	WPS No. 18
Welding Process	SMAW	GTAW	GTAW	GTAW	GTAW	GTAW	GTAW	GTAW	GTAW
Base Metal	Mild steel 1010-1020	4130	4130	4130	321 SS	321 SS	INCO 718	INCO 718	6061 T6
Thickness	0.250 sheet	0.032	0.125	0.125	0.020	0.032	0.125	0.040	0.032
Joint Description	Butt joint in sheet	Butt joint in sheet	Butt joint in sheet	T joint in sheet	Butt joint in sheet	Butt joint in sheet	Butt joint in sheet	Butt joint in sheet	Butt joint in sheet
Weld Type	Single V groove - multiple passes	Single Square Groove, One Pass	Single V Groove, Two Passes	Fillet, One Pass, One Side, Max. Length 0.18	Single Square Groove, One Pass	Single Square Groove, One Pass	Single Square Groove, One Pass	Single Square Groove, One Pass	Single Square Groove, One Pass
Joint Clearance	None	None	0.62 Max	0.62 Max	None	None	0.62 Max	None	None
Backing	None	None	None	None	None	None	None	None	None
Weld Position	1G (Flat)	1G (Flat)	1G (Flat)	2F (Horizontal)	1G (Flat)	1G (Flat)	1G (Flat)	1G (Flat)	1G (Flat)
Weld Progression	Forehand	Forehand	Forehand	Forehand	Forehand	Forehand	Forehand	Forehand	Forehand
Filler Metal	ER 7018	4130	4130	4130	347	347	AMS 5832	AMS 5832	4043
Diameter	3/32"	0.045	0.062	0.062	0.030	0.045	0.063	0.045	0.062
Shielding Gas	None	Argon 20 CFH	Argon 25 CFH	Argon 20 CFH	Argon 15 CFH	Argon 15 CFH	Argon 20 CFH	Argon 20 CFH	Argon 25 CFH
Nozzle Size	N/A	#6	#6	#6	#6	#6	#6	#6	#6
Root Shielding Gas	N/A	Argon 10 CFH	Argon 10 CFH	Argon 10 CFH	Argon 10 CFH	Argon 10 CFH	Argon 10 CFH	Argon 10 CFH	Argon 10 CFH
Current	DCEP/80-100 amps	DCEN 0/30 amps	DCEN 0/80 amps	DCEN 0/69 amps	DCEN 0/18 amps	DCEN 0/32 amps	DCEN 0/70 amps	DCEN 0/33 amps	AC-HF 0/35 amps
Electrode/ Size	ER 7018 3/32"	AWS EWTh2/ EWCe-2/ EWLa-1, 0.063	AWS EWTh2/ EWCe-2/ EWLa-1, 0.063	AWS EWTh2/ EWCe-2/ EWLa-1, 0.063	AWS EWTh2/ EWCe-2/ EWLa-1, 0.063	AWS EWTh2/ EWCe-2/ EWLa-1, 0.063	AWS EWTh2/ EWCe-2/ EWLa-1, 0.063	AWS EWTh2/ EWCe-2/ EWLa-1, 0.063	AWS EWTh2/ EWCe-2/ EWLa-1/ EWZr-1, 0.040
Remarks	See Note #2 and # 3	See Note #3	See Note #3	See Note #3	See Note #3	See Note #3	See Note #3	See Note #3	See Note #3

Note 1: Incline position. The position of a tube joint in which the axis of the tube is approximately at an angle of 45° to the horizontal, and the tube is not rotated during welding.
Note 2: Joint prepared by machining edges, grinding and degreasing
Note 3: Postweld heat treatment not required

Table 3-3. Welding Procedure Specifications (Cont.)

	WPS No. 19	WPS No. 20	WPS No. 21	WPS No. 22	WPS No. 23	WPS No. 24	WPS No. 25	WPS No. 26
Welding Process	GTAW	GTAW	GTAW	GTAW	GTAW	GTAW	GTAW	GTAW
Base Metal	6061-T6	6061-T6	AZ92A	AZ92A	AZ92A	Ti-6A1-4V	Ti-6A1-4V	L605
Thickness	0.125	0.020	0.032	0.125	0.020	0.040	0.125	0.016
Joint Description	Butt joint in sheet	Butt joint in sheet	Butt joint in sheet	Butt joint in sheet	T joint in sheet	Butt joint in sheet	T joint in sheet	Butt joint in sheet
Weld Type	Single V Groove, Two Passes	Single V Groove, Two Passes	Single Square Groove, One Pass	Single Square Groove, One Pass	Single Square Groove, One Pass	Single Square Groove, One Pass	Single V Groove, Two Passes	Single Square Groove, One Pass
Joint Clearance	0.092	None	None	0.092	None	None	0.062 Max	None
Backing	None	None	None	None	None	None	None	None
Weld Position	1G (Flat)	1G (Flat)	1G (Flat)	1G (Flat)	1G (Flat)	1G (Flat)	1G (Flat)	1G (Flat)
Weld Progression	Forehand	Forehand	Forehand	Forehand	Forehand	Forehand	Forehand	Forehand
Filler Metal	4043	4043	AMS 4395	AMS 4395	AMS 4954	AMS 4954	AMS 4954	AMS 5796
Diameter	0.125	0.045	0.045	0.125	0.045	0.045	0.062	0.030
Shielding Gas	Argon 20 CFH	Argon 25 CFH	Argon 20 CFH	Argon 20 CFH	Argon 25 CFH	Argon 30 CFH	Argon 40 CFH	Argon 15 CFH
Nozzle Size	#7	#6	#6	#6	#12	#12	Modified cup 2" diameter	1/4
Root Shielding Gas	Argon 10 CFH	None	Argon 10 CFH	Argon 10 CFH	None	Argon 10 CFH	Argon 20 CFH	Argon 10 CFH
Current	AC-HF 0/125 amps	AC-HF 0/28 amps	AC-HF 0/28 amps	AC-HF 0/65 amps	AC-HF 0/13 amps	DCEN 0/39 amps	DCEN 0/70 amps	DCEN 0/23 amps
Electrode/ Size	AWS EWTh2/ EWCe-2/ EWLa-1/ EWZr-1, 0.063	AWS EWTh2/ EWCe-2/ EWLa-1/ EWZr-1, 0.063	AWS EWTh2/ EWCe-2/ EWLa-1/ EWZr-1, 0.063	AWS EWTh2/ EWCe-2/ EWLa-1/ EWZr-1, 0.063	AWS EWTh2/ EWCe-2/ EWLa-1/ EWZr-1, 0.063	AWS EWTh2/ EWCe-2/ EWLa-1/ EWZr-1, 0.063	AWS EWTh2/ EWCe-2/ EWLa-1/ EWZr-1, 0.063	AWS EWTh2/ EWCe-2/ EWLa-1/ EWZr-1, 0.063
Remarks	See Note #3	See Note #3	See Note #2 and #3	See Note #2 and #3	See Note #2 and #3	See Note #3	See Note #3	See Note #3

Note 1: Incline position. The position of a tube joint in which the axis of the tube is approximately at an angle of 45° to the horizontal, and the tube is not rotated during welding.

Note 2: Joint prepared by machining edges, grinding and degreasing

Note 3: Postweld heat treatment not required

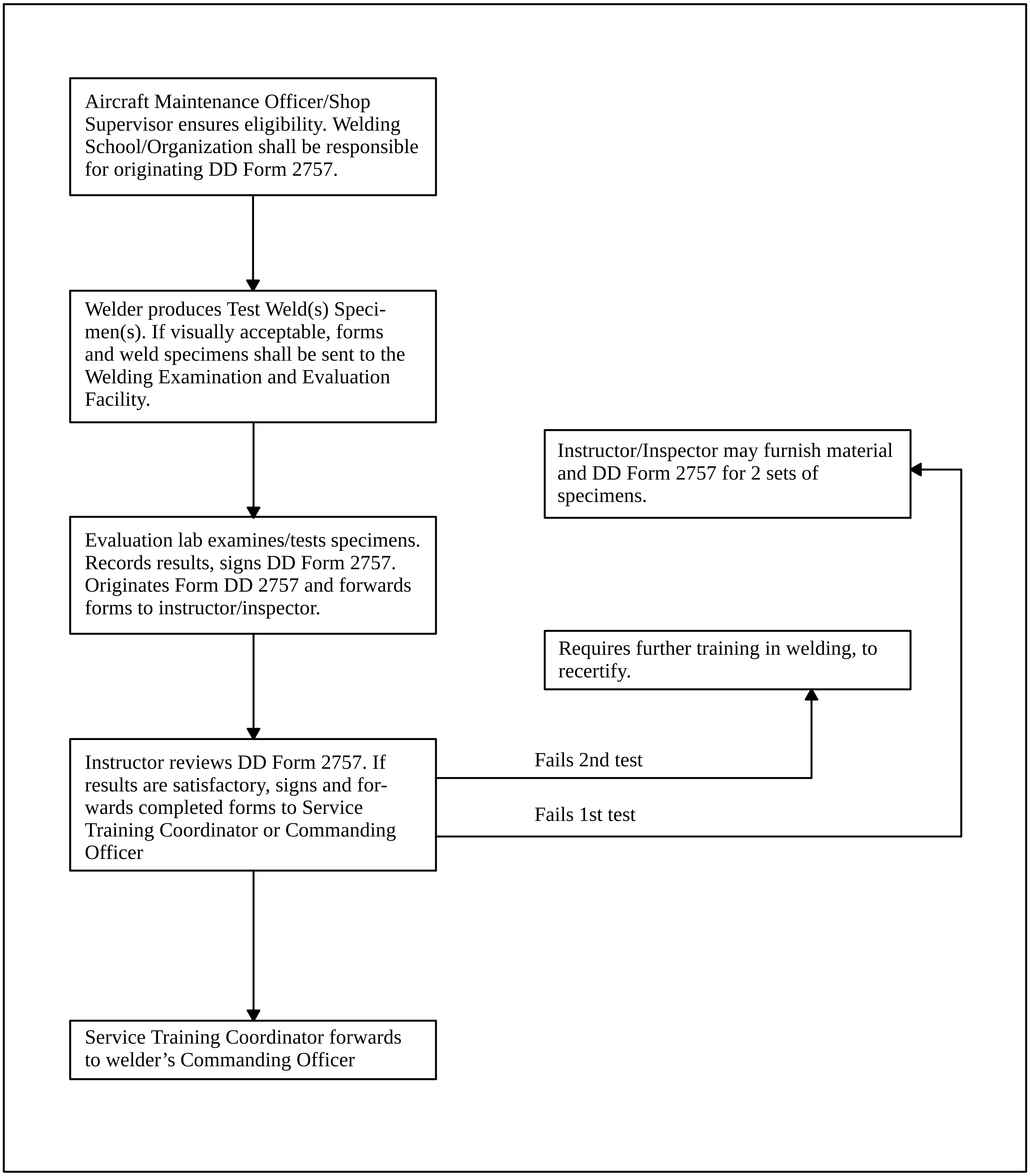


Figure 3–2. Certification/Recertification Sequence Chart

WELDING EXAMINATION RECORD

1. DATE

SECTION I - APPLICATION

2. NAME *(Last, First, Middle Initial)*		3. PARENT ORGANIZATION	4. UNIT ADDRESS
5. QUALIFICATION GROUP	6. RATING/RATE	7. WELDER IDENTIFICATION NUMBER	8. EXPIRATION DATE
9. WELDING SCHOOL OR SOURCE OF TRAINING		10. WELDING PROCESS	

11. WELDING PROCEDURE SPECIFICATIONS *(See Table 3-3 for all parameters. Use a. - n. for special qualifications)*	WPS NUMBERS								
a. BASE METAL									
b. FILLER METAL TYPE									
c. FILLER METAL DIAMETER									
d. POSITION									
e. TORCH SHIELDING GAS TYPE									
f. TORCH SHIELDING GAS FLOW									
g. ROOT SHIELDING GAS TYPE									
h. ROOT SHIELDING GAS FLOW									
i. NOZZLE SIZE									
j. CURRENT TYPE									
k. AMPERAGE									
l. ELECTRODE TYPE									
m. ELECTRODE DIAMETER									
n. NUMBER OF PASSES									

12. SIGNATURE OF APPLICANT	13. SIGNATURE OF OBSERVING OFFICIAL. I certify the weld specimen was completed by the applicant using the above procedure.

SECTION II - EXAMINATION RESULTS

WPS NUMBERS	TEST SPECIMEN				RETEST SPECIMEN			
	14. VISUAL	15. RADIOGRAPHIC	16. BEND	17. METALLOGRAPHIC	14. VISUAL	15. RADIOGRAPHIC	16. BEND	17. METALLOGRAPHIC

18. REMARKS

19. TO OBTAIN REQUALIFICATION OPERATOR MUST:

☐ RESUBMIT EXAMINATION ☐ ATTEND AUTHORIZED WELDING TRAINING SCHOOL

20. TESTING OFFICIAL ☐ QUALIFIED ☐ NOT QUALIFIED	a. SIGNATURE	
b. ORGANIZATION AND ADDRESS	c. QUALIFICATION GROUP	d. LEVEL *(AF only)*
21a. SIGNATURE OF CERTIFYING OFFICIAL		b. DATE CERTIFIED

DD FORM 2757, JUN 1997

Figure 3–3. Welding Examination Record (Sheet 1 of 2)

INSTRUCTIONS FOR COMPLETION OF DD FORM 2757.
WELDING EXAMINATION RECORD

SECTION I:

Block 2 - NAME. Self-explanatory.

Block 3 - PARENT ORGANIZATION. Self-explanatory.

Block 4 - UNIT ADDRESS. Self-explanatory.

Block 5 - QUALIFICATION GROUP. Metal groups submitted for certification.

Block 6 - RATING/RATE. Enter military rank or civilian pay number.

Block 7 - WELDER IDENTIFICATION NUMBER. Enter military identification number or civilian pay number.

Block 9 - WELDING SCHOOL OR SOURCE OF TRAINING. Self-explanatory.

Block 10 - WELDING PROCESS. Process used to accomplish the weld.

Block 11 - WELDING PROCEDURE USED. Conditions used in completing test welds will be listed under appropriate WPS number column (See Table 3-3).

Block 12 - SIGNATURE OF APPLICANT. Self-explanatory.

Block 13 - SIGNATURE OF OBSERVING OFFICIAL. Signature of the person observing the certification welding.

Blocks 14 - 17. The appropriate blocks will be marked either satisfactory (SAT) or unsatisfactory (UNSAT) in accordance with the results of the particular examination.

Block 18 - REMARKS. Record cause of any unsatisfactory results or other relevant information.

Block 19 - TO OBTAIN REQUALIFICATION OPERATOR MUST. Decision made by evaluating activity after failure of previous test specimens.

Block 20 - TESTING OFFICIAL. Annotate whether qualified or not qualified in appropriate box (All DOD). Signature of the official who evaluates the test specimens. Organization and address of testing official.

Block 21 - CERTIFYING OFFICIAL. The welding instructor/inspector who actually certifies the welder at the evaluation laboratory will enter signature and record the effective date of

DD FORM 2757 (BACK), JUN 1997

Figure 3-3. Welding Examination Record (Sheet 2 of 2)

WELDING CERTIFICATION CARD

NAME WELDER IDENTIFICATION NO.

is certified in accordance with NA 01-1A-34/TO 00-25-252/TC 9-238/ AWS B2.1 for the welding processes, metal groups, thicknesses and positions that are listed and initialed/stamped on the back of this card.

DATE AUTHORIZED ENG. LAB SIGNATURE

DATE WELD INSTRUCTOR/INSPECTOR SIGNATURE

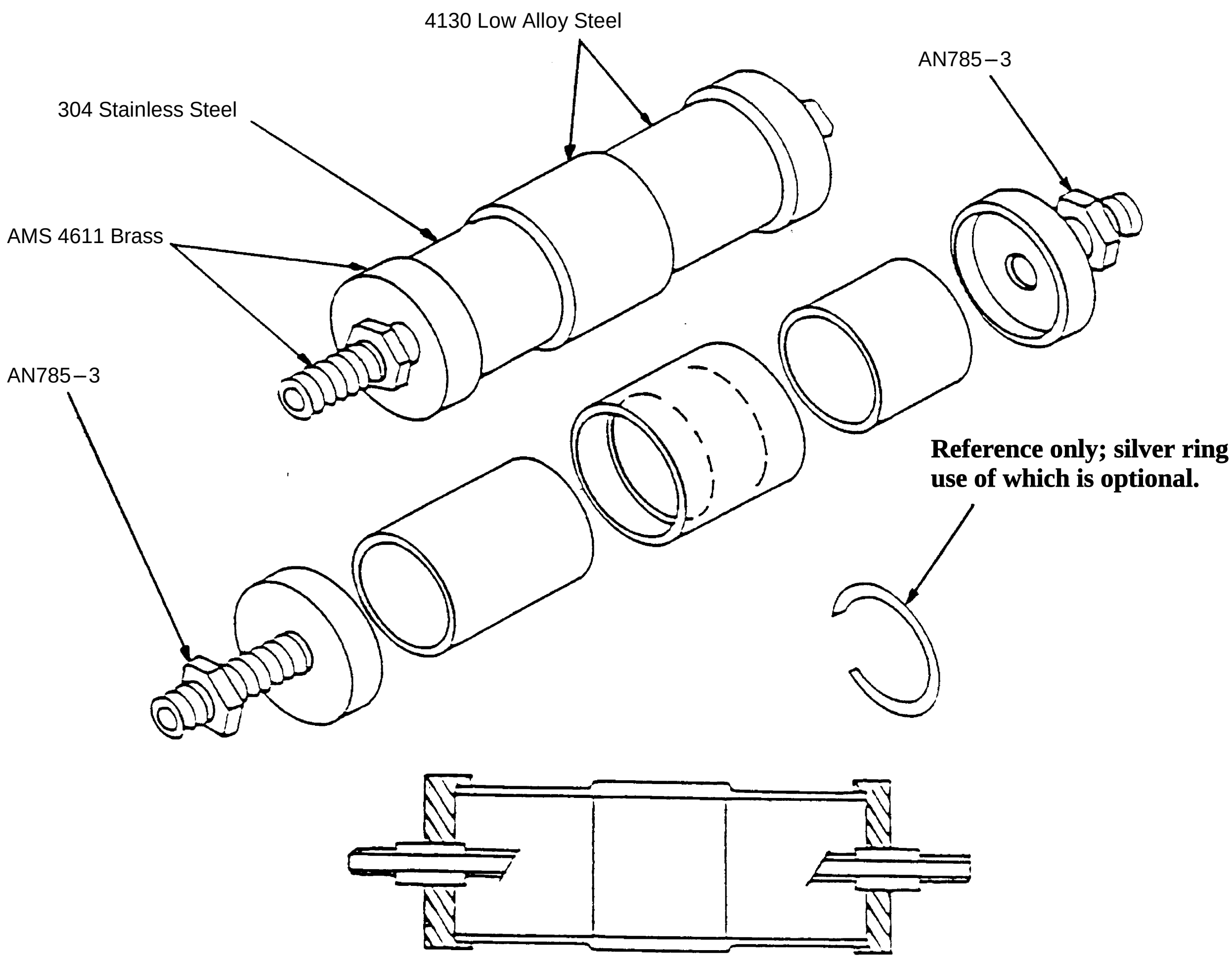
CERTIFYING ACTIVITY

DD FORM 2758, JUN 1997

PROCESS	METAL GROUP	THICKNESS LIMITATIONS	POSITIONS	INITIAL/ STAMP	EXP. DATE

DD FORM 2758 (BACK), JUN 1997

Figure 3–4. Welding Certification Card

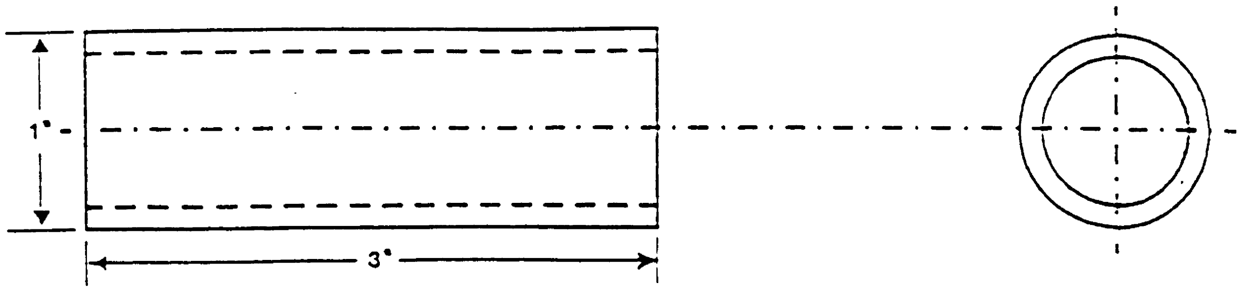


HALF SECTION

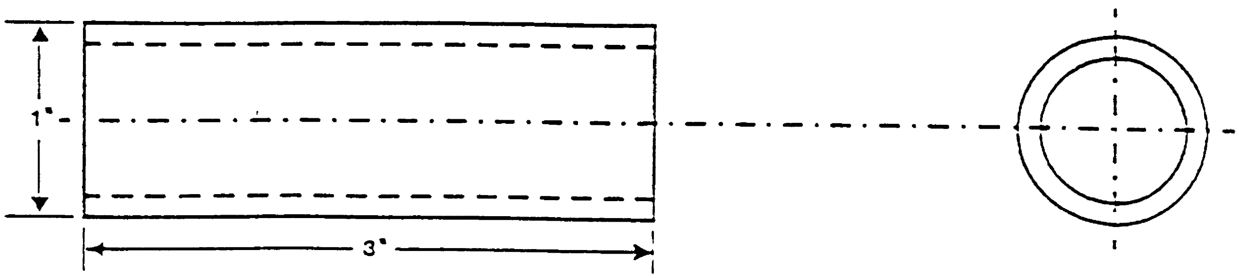
NOTES

1. Welding Schools listed in Table shall furnish P/N AN 785-3 as shown in the middle diagram and specimens as shown in Figure 3-4 (Sheet 2)
2. Braze Operator
   a. Manufacture silver solder ring shown in separate right hand section if the use of this optional item is determined.
   b. Braze specimens as shown in upper diagram.
3. Authorized examination and evaluation facility:
   a. Pressure test finished assembly with 3000 psi for leaks with MIL-H-83282 hydraulic fluid or equivalent.
   b. Prepare specimen for evaluation by sawing or otherwise cutting in two as shown in the lower diagram.

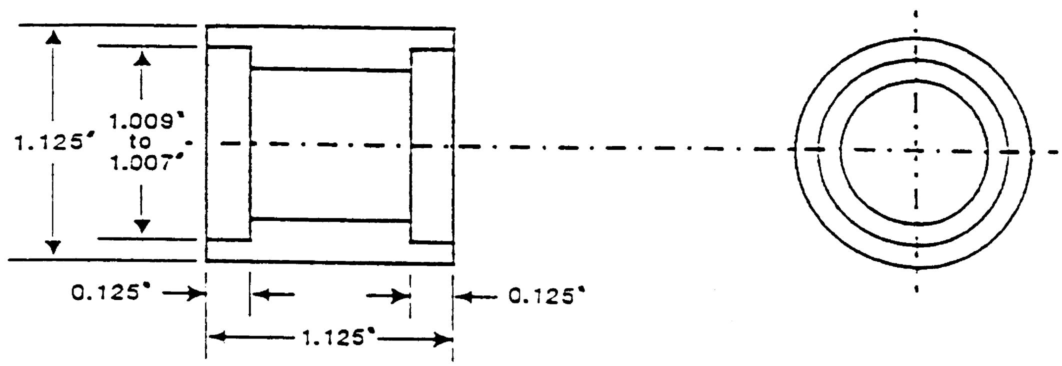
Figure 3-5. Specimen Requirement for Silver Brazing (Sheet 1 of 2)



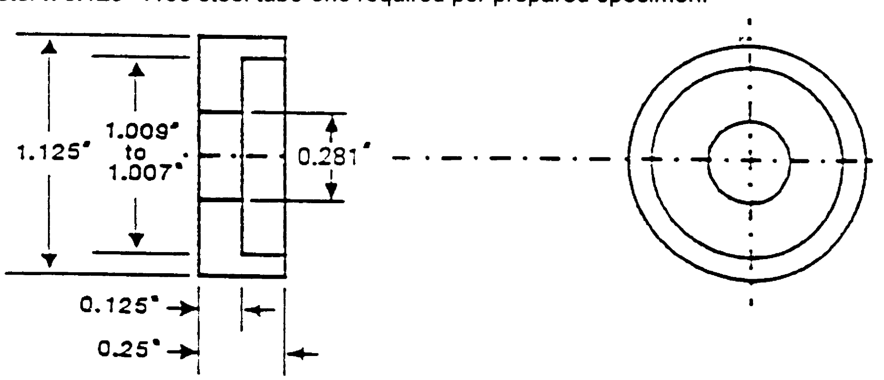
1" outer diameter x 0.049" x 3" 4130 steel tube-one required per prepared specimen.



1" outer diameter x 3" x 0.049" staiinless steel tube-one required per prepared specimen.

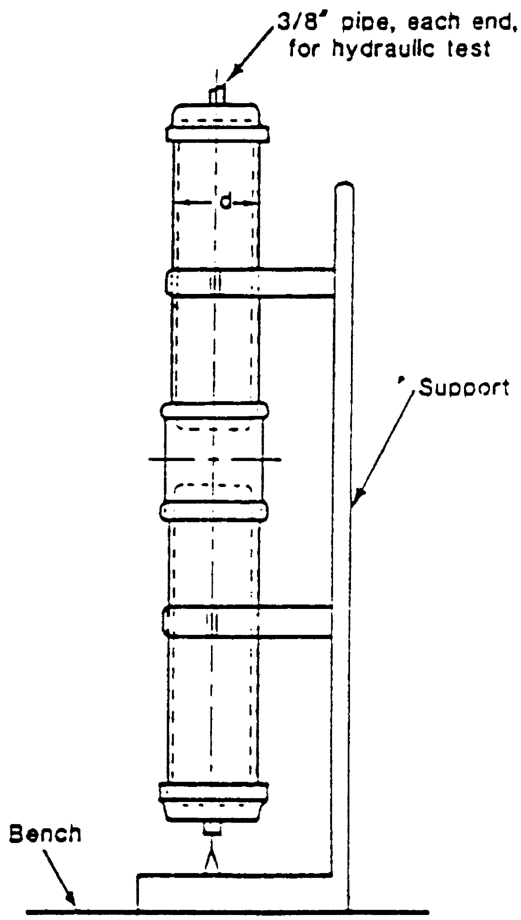


1.125" outer diameter x 0.120" 4130 steel tube-one required per prepared specimen.



1.125" outer diameter brass rod-two required per prepared specimen.

Figure 3–5. Specimen Requirement for Silver Brazing (Sheet 2 of 2)



NOTES

1. Workmanship sample brazed in the vertical position shall qualify for all brazing positions.
2. Specimen to be hydraulic pressure tested 3,000 to PSI for 10 minutes. No leakage or weepage permitted.
3. Specimen shall not be rotated during brazing operations.

Figure 3–6. Vertical Position Brazed Workmanship Sample

3.13.1.6 . Joint Description. No change permitted. Essential

3.13.1.7 Weld Type. No change permitted. Essential.

3.13.1.8 Joint Clearance. Nonessential.

3.13.1.9 Backing. No change permitted. Essential.

3.13.1.10 Weld Position. No change permitted. Essential.

3.13.1.11 Welding Progression. Essential.

3.13.1.12 Filler Metal Composition. No change permitted. Essential.

3.13.1.13 Filler Metal Diameter. Nonessential.

3.13.1.14 Shielding Gas. Essential.

3.13.1.15 Root Shielding Gas. Essential.

3.13.1.16 Nozzle Size. Nonessential.

3.13.1.17 Current Type. No change permitted. Essential.

3.13.1.18 Welding Amperage. Nonessential.

3.13.1.19 Electrode. Nonessential.

NOTE

Suggested fixtures are illustrated in this section. Clamps, tack welds of other holding devices are permitted.

3.13.1.20 Fixtures. The use of a fixture is not required, but is permitted, provided that no support for molten weld metal is present. Essential

3.14 BASE METALS.

The following base metals are required for certification of GTAW, GMAW, SMAW and brazing processes for most aircraft and missile welders. Table 3–2 lists all possible base metals in which a welder can be certified. It is the decision of the individual service to choose the required metals for their particular applications. See paragraphs 3.16, 3.17 and 3.18 for service peculiar requirements.

3.14.1 GTAW. The base metal groups listing are shown in Tables 3–2 and 3–3, and a complete breakdown of those groups is included in the base metal groups listing.

3.14.2 GMAW/SMAW. 1010–1020 mild steel (Group I).

3.14.2.1 Brazing.

a. 4130 low alloy steel (Group II).

b. 304 stainless steel (Group III).

c. Brass (AMS 4611).

3.15 CERTIFICATION MATERIALS AND PROCEDURES.

A welder shall certify to position 6G per MIL–STD–1595 for every metal group as described below.

NOTE

Refer to Figure 3–9 for materials, dimensions and NSNs of certification tubes.

3.15.1 GTAW. Position 6G is illustrated in Figure 3–7. It consists of one inch diameter tubing, 4 inches long, with a wall thickness of 0.050 inch for every metal group. The tubing is cut in 4 inch lengths, then deburred and cleaned and tacked together (on the bench) in three places around the joint circumference. The tube assembly is then slipped over the end of the weld fixture described in Figure 3–8. Once in place the tube shall not be rotated. The welder then welds the entire joint in this position. Only the fixture can be moved around to accommodate welder comfort provided the tube stays in the 6G position.

NOTE

Successful certification on these tubes also certifies the welder for t (0.025”) through 2t (0.100”) thick materials.

3.15.2 GMAW and SMAW. Certification procedures for GMAW and SMAW will be as a minimum accomplished in the 1G position as illustrated in Figure 3–1, or as determined by service command. Sheet thickness shall be 0.250”. Back up bars are not allowed for this certification.

NOTE

Successful certification on this sheet will limit the welder to weld in position 1G, 1F, 2F in sheet and 1G, 1F in pipe and material thicknesses ranging from 0.125” to 0.50”. (See Table 3–1).

3.15.3 Brazing. Refer to paragraph 3.12.6 for details.

3.16 AIR FORCE UNIQUE CERTIFICATION REQUIREMENTS.

The USAF has specific, established procedures and requirements that differ from the USN and the USA.

3.16.1 Levels of Certification. Civilian welders assigned to ALCs may be divided into a position/material certified welder, Level I, or Level II welders. Each type of certification is described below:

3.16.1.1 Position/Material Certified Welder. This individual is qualified to specific processes or positions for a given material group. Usually this welder is performing a specific task. Qualification of the WPS (for certification) will be accomplished by the cognizant engineer using the requirements of MIL–STD–1595 or AWS B2.1.

3.16.1.2 Level I. Level I is attained by qualifying to two or more basic positions within a base metal group. Usually 1G (flat) and 2F (horizontal) positions are required to meet Level I. Each ALC will determine what positions and base metal groups are required to achieve this level of certification.

3.16.1.3 Level II. Level II is attained by qualifying to the 6G position within a base metal group. An individual does not have to be Level I certified prior to achieving Level II certification. Each ALC will determine what base metal groups are required to achieve this level of certification.

3.16.2 Military, reserve and Air National Guard will qualify to the 6G position. The MAJCOM Fabrication Superintendent or designation shall establish which base metal groups are required for certification. Base Metal groups may vary by operating location.

3.16.3 Recertification Intervals.

a. ALC (civilians 5 years).

b. Field (5 years).

3.16.4 Fixtures for flat sheet welding. Table 3–4 is the listing of fixture drawing numbers. Figures 3–10 and 3–11 describe the butt and t–joint welding fixtures.

3.16.5 Welding Examination Record. Field units will use the DD Form 2757 (see Figure 3–3). ALC civilians will use same form (see Figure 3–3).

3.16.6 Welding Examination and Evaluation. Weld certification specimens may be examined by properly equipped and trained unit Nondestructive Inspection (NDI) laboratories or servicing ALCs.

Table 3–4. Welding Fixture Drawing Chart

FIXTURE	DRAWING NO.
Butt Joint Welding Assembly	8030688
Butt Joint Welding Clamp	8030689
Butt Joint Welding Base Assembly	8030683
Butt Joint Welding Base	8030690
T Joint Welding Assembly	8030682
T Joint Welding Base	8030690
T Joint Welding Base Assembly	8030693
T Joint Welding Base Assembly	8030684
T Joint Welding Clamp Assembly	8030685
T Joint Welding Clamp	8030686
Note: Fixture drawings are available from WR–ALC/MMEDDA	

3.16.6.1 Observing Official. The observing official is responsible for ensuring that section I of DOD form 2757 accurately reflects the welder's identifying information and the welding parameters used for the test weld specimen. Upon completion of the subject weld, the observing official will sign block 13 acknowledging that the welding procedures were performed in accordance with the specific WPS and this technical order.

3.16.6.2 Examining Official. The examining official is responsible for performing all visual, radiographic, bend and metallographic tests required for the applicable WPS. The examining official will enter SAT, UNSAT or NA appropriately in blocks 14–17 of section II of the DD Form 2757 for each test. Upon completion of the weld specimen evaluations, the examining official will complete the remaining information in blocks 18–20, initial the qualified or not qualified block as applicable, and sign block 20a. acknowledging that the tests were performed in accordance with this technical order. For each metal group successfully completed, the examining official will enter appropriate information on the DOD Form 2758 (cert card) and date/sign the authorized engineering lab signature line. A copy of DOD Form 2757 will be kept on file by the examining official for not less than 5 years with the original DOD Form 2757 and DOD Form 2758 being returned to the submitting unit.

3.16.6.3 Welder's Supervisor. The welder's supervisor will review DOD Form 2757 and DOD Form 2758. If the welding tests were successful, the supervisor will date and sign the DOD Form 2758 on the weld instructor signature line and forward a complete package to the certifying official for final review. If the test welds were unsuccessful, the supervisor will interview the welder to develop and recommend appropriate training/administrative actions. The welder's supervisor is responsible for maintaining the completed DOD Form 2757 in the welder's training, personnel or other readily accessible file. DOD Form 2758 may be carried by the welder or kept in a readily accessible file. The welder's supervisor will ensure a current DOD Form 2758 accompanies the welder on any deployments.

3.16.6.4 Certifying Official. The welding inspector who actually certifies the welder at the evaluation laboratory. The certifying official will sign block 21a. and date block 21b. of the DOD Form 2757 and sign the welding inspector line for the certifying activity on the DOD Form 2758. For initial certification unit commanders should consider formal presentation of the DD Form 2758 to the metals technology technician in recognition of their accomplishment.

3.17 NAVAL AIR UNIQUE CERTIFICATION REQUIREMENTS.

The Naval Aviation component of the USN has specific, established procedures and requirements that differ from the USAF and USA.

3.17.1 General. Naval aviation welders may be required to certify in the following processes:

a. Gas Tungsten Arc Welding (GTAW).

b. Gas Metal Arc Welding (GMAW).

c. Shielded Metal Arc Welding (SMAW).

d. Oxyfuel Brazing (OFB).

To become qualified as a welder or torch brazer, an individual must be trained, tested and certified under this manual and MIL–STD–1595 (GTAW and GMAW) and/or MIL–STD–248 (oxygen–fuel torch brazing), as applicable. Training courses presented at the Naval Aviation Depots (NAVAVNDEPOT), meet these requirements (see Table 3–5). Other service schools or learning institutions training to the specifications listed are suitable. Testing and certification must be accomplished within the guidelines listed in the OPNAVINST 4790.2 and this manual. Recertification of welders/torch brazers previously certified in accordance with this manual or MIL–STD–1595 shall be achieved by producing acceptable test welds/brazed joints to an authorized examination and evaluation facility (see Table 3–6) or successfully completing requalification courses N–701–0008 or N–701–0010 per Table 3–5.

3.17.2 Certification Procedures. Refer to paragraph 3.8 for certification procedures.

3.17.3 Naval Air Welders Proficiency Log. In order to maintain qualification and certification, every welder must perform actual component welds and/or practice welds on a continuing basis for each process and metal group. Documentation of practice and actual component welding will be in the welder's log (see Figure 3–12) and will be verified by the workcenter supervisor at least quarterly (90 days). If the work center supervisor is a welder, he/she will be monitored by Quality Assurance. If a welder is unable to, or does not document actual component or practice welds for each process and metal group for a period of six months (180 days), he/she must recertify in accordance with paragraph 3.10.

a. The welder's log shall be filled out per Figure 3–12 (Sheet 2).

3.17.4 Intermediate and Organizational Level Welding Recertification Requirements. A certified welder shall recertify when one of the following conditions apply:

a. Three years have passed since last certification/recertification.

b. The welder fails to maintain the welder's proficiency log as described in paragraph 3–17.3.

c. There is specific reason to question the ability of a welder or welding operator to meet the requirements for certification in a given welding process. Specific reasons may include: poor quality welds, eyesight acuity, health and behavior.

d. The welder fails retesting as described in Figure 3–2.

3.17.5 Recertification Procedures. (See Figure 3–2 for Recertification Sequence Chart)

a. The welder must possess a current welding certificate in the appropriate category.

b. The activity maintenance officer, after ensuring the welder is eligible for recertification, shall order by letter the required test specimens from the nearest welding school (see Table 3–5), providing the following information:

(1) Welder's Name

(2) Certification expiration date.

(3) Categories required for recertification.

(4) Examination and evaluation facility of last certification.

Table 3–5. Welding Schools and Course Numbers

COURSE NUMBER	TITLE	COURSE LENGTH
N–701–0007	A/C Support Equipment Basic Welder Qualification (to NEC 7223 is applicable to rate)	Refer to CANTRAC
N–701–0008	Requalification for N–701–0007	
N–701–0009	Oxyfuel, Brazing, Shielded Metal Arc Welder Qualification (to NEC 7222 if applicable to rate)	
N–701–0010	Requalification for N–701–0009	
N–701–0025	GMAW Welder Certification	
NOTE Refer to CANTRAC for other course numbers.	Norfolk Naval Shipyard Attn: Nuclear/NAVAIR Welding School Portsmouth, VA 23709–5000	
	NAVAVNDEPOT Jacksonville, FL	
	NAVAVNDEPOT Cherry Point, NC	
	NAVAVNDEPOT North Island, CA	

Table 3–6. List of Authorized Welding Examination and Evaluation Facilities

NAVAVNDEPOT NAS Jacksonville, FL 32212 (ATTN: Materials Engineering Division)
NAVAVNDEPOT MCAS Cherry Point, NC 28533 (ATTN: Materials Engineering Division)
Mid–Atlantic Regional Calibration and Materials Test Lab (ATTN: Materials Engineering Branch) 9349 Forth Ave. Norfolk, VA 23511–2116 (ATTN: Materials Engineering Division)
NAVAVNDEPOT NAS North Island, San Diego, CA 92135 (ATTN: Materials Engineering Division)
For activities in the Point Mugu area only: Pacific Missile Test Center Point Mugu, CA 93042 (ATTN: Quality Control Officer, Code 4000, Engineering Materials Testing Laboratory, Technical Shop Division, Box 10)

c. Complete an accurate return mailing address (including commercial and DSN phone numbers).

d. Test specimen materials for certification/recertification shall be prepared and furnished by the welding school. The welder identified on the specimen shall weld the specimen in the welder's normal duty shop. The shop supervisor or maintenance officer, shall assure that each specimen is welded by the welder identified on the specimen, and returned to the welding instructor at one of the examination facilities listed in Table 3–6. A complete certification/recertification procedural flow chart is described in Figure 3–2.

e. Initial certification of welders must be done at one of the NAVAVNDEPOTs listed in Table 3–6.

f. Intermediate Maintenance Activity (IMA) Welders may get trained, tested and certified by attending the basic metal welding school (electric arc and inert gas welding) listed in Table 3–5 and the Catalog of Naval Training Courses (CANTRAC), NAVEDTRA 10500. This course will lead to designation of NEC/MOS 7222/6043. Welders requiring training in other process/metal groups in addition to the basic welding course must request authorization for such training from the cognizant TYCOM/ACC via the chain of command. The oxyfuel torch brazing course provides training, testing and certification in this discipline. This training/certification alone does not lead to an NEC/MOS.

NOTE

Refer to Table 3–5 and the Catalog of Naval Training Courses (CANTRAC), NAVEDTRA 10500, for training courses.

g. IMA welders trained outside the depot may obtain initial certification by completing the requalification course listed in Table 3–5.

h. IMA welders must recertify to the standards listed in paragraph 3.10 at one of the depots listed in Table 3–6. Individuals being detailed on permanent change of station (PCS) orders should be routed via one of the depots for recertification.

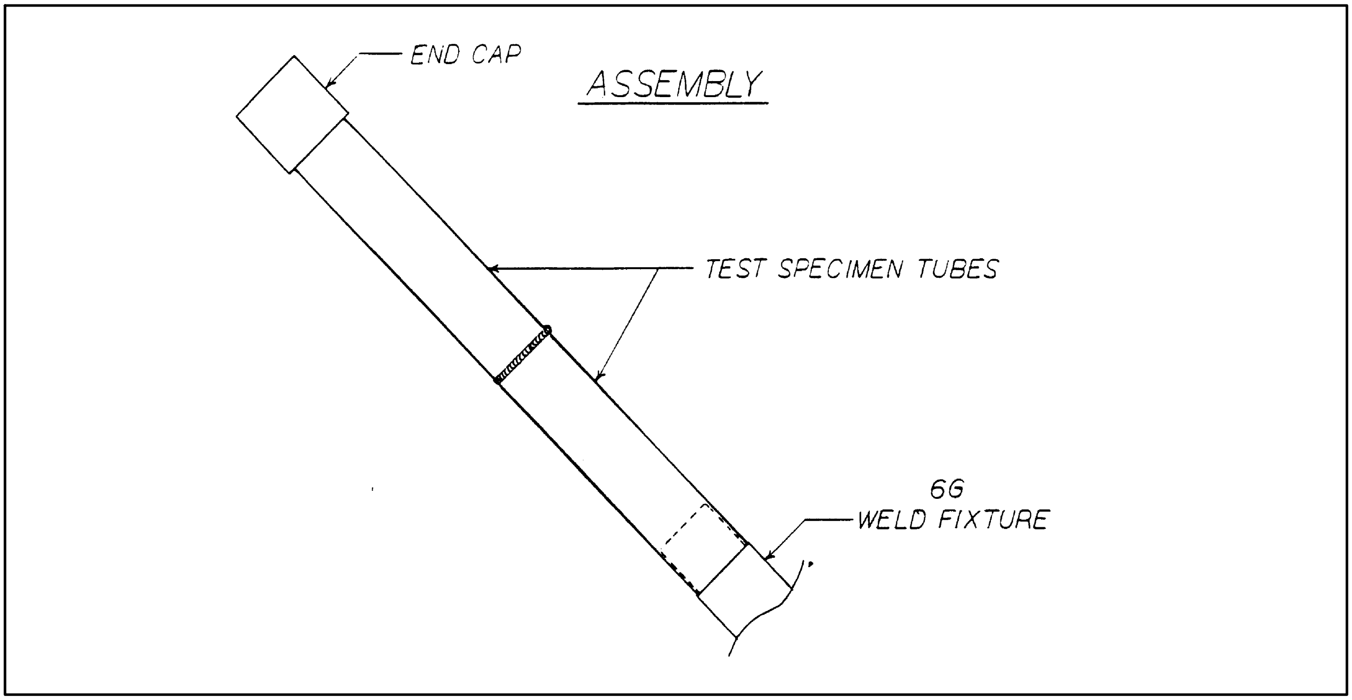


Figure 3-7. Position 6G

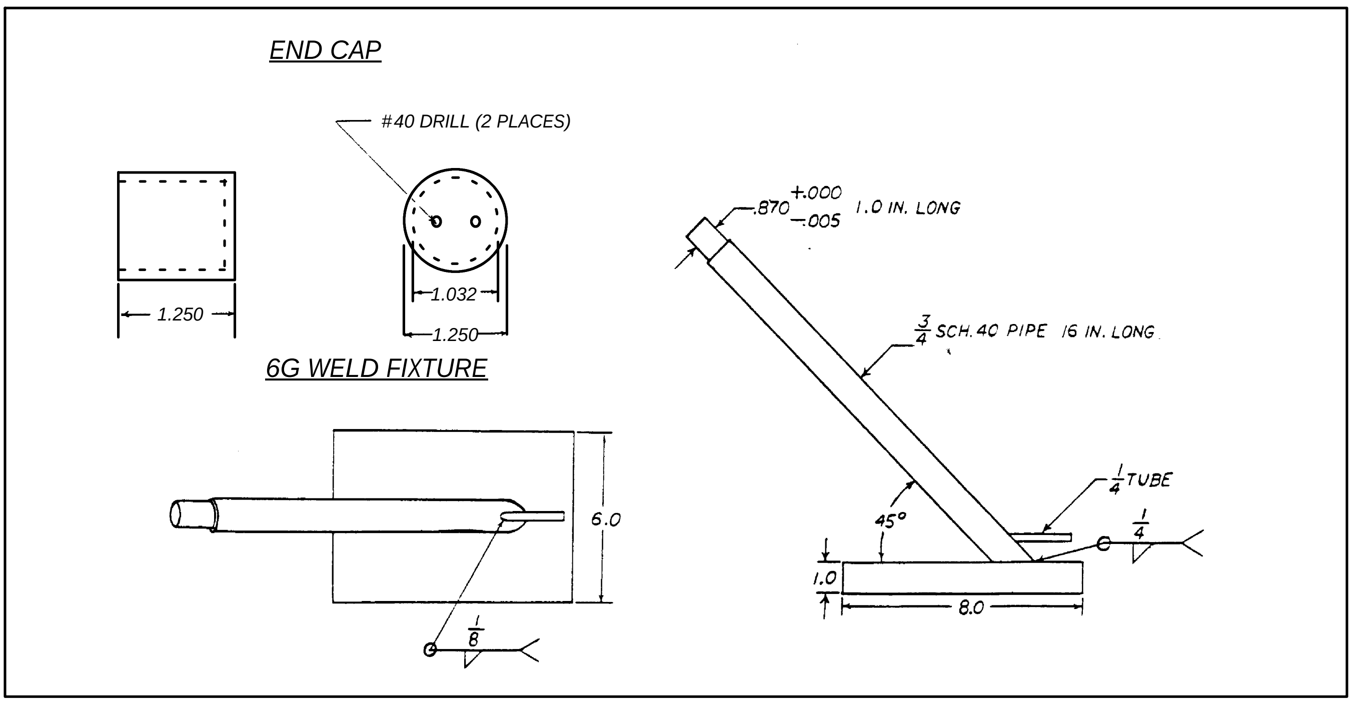
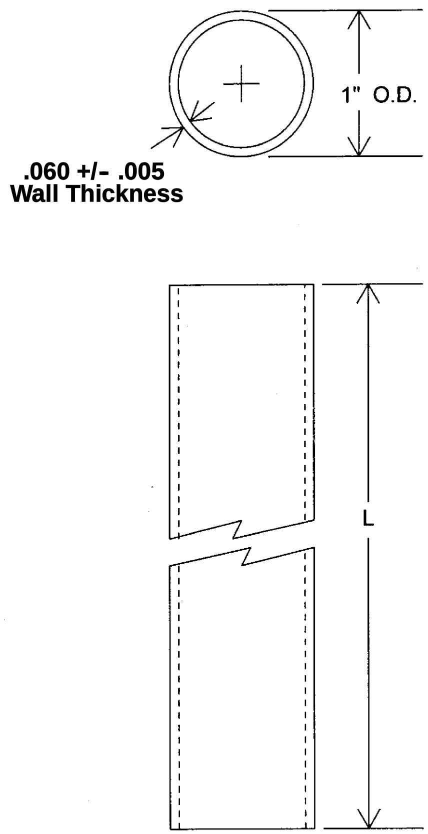


Figure 3-8. Top View, Side View and End Cap



Dash #	Material	NSN	"L" (min)
- 1	AISI 4130 Cond. "N" Low Alloy Steel	4710-00-277-9887	60"
- 2	AISI 347 Stainless Steel Annealed	4710-00-585-7053	96"
- 3	AA 6061 T6 Aluminum Alloy	4710-00-289-3036	96"
- 4	3AL 2.5V Titanium Alloy Annealed	4710-00-345-8474	60"
- 5	Inconel 718 Nickel Alloy Annealed	4710-01-425-0916 P/N 52-12-5	30" to 48"
- 6	L605 Cobalt Alloy Annealed	4710-01-425-0937 P/N 52-20-10	30" to 48"
- 7	AZ31B-F Magnesium Alloy	4710-01-425-0901 P/N 3-1-02	30" to 48"

Notes:

1. Seamless or Welded Tubing

MATERIALS ENGINEERING LABORATORY U.S NAVAL AIR STATION NORTH ISLAND - SAN DIEGO, CALIF. BY: MIKE POIRIER - CODE 43430 -EX-57828	TOLERANCES UNLESS OTHERWISE SPECIFIED FRACTIONAL ± 1/32 DECIMAL .X = +/- .030 .XX = +/- .010 .XXX = +/- .005 ANGULAR ± 30' DATE: 12/20/95 REVISED: XX/XX/XX	WELD CERTIFICATION TUBE SK340-00185

Figure 3–9. Certification Material and Dimensions

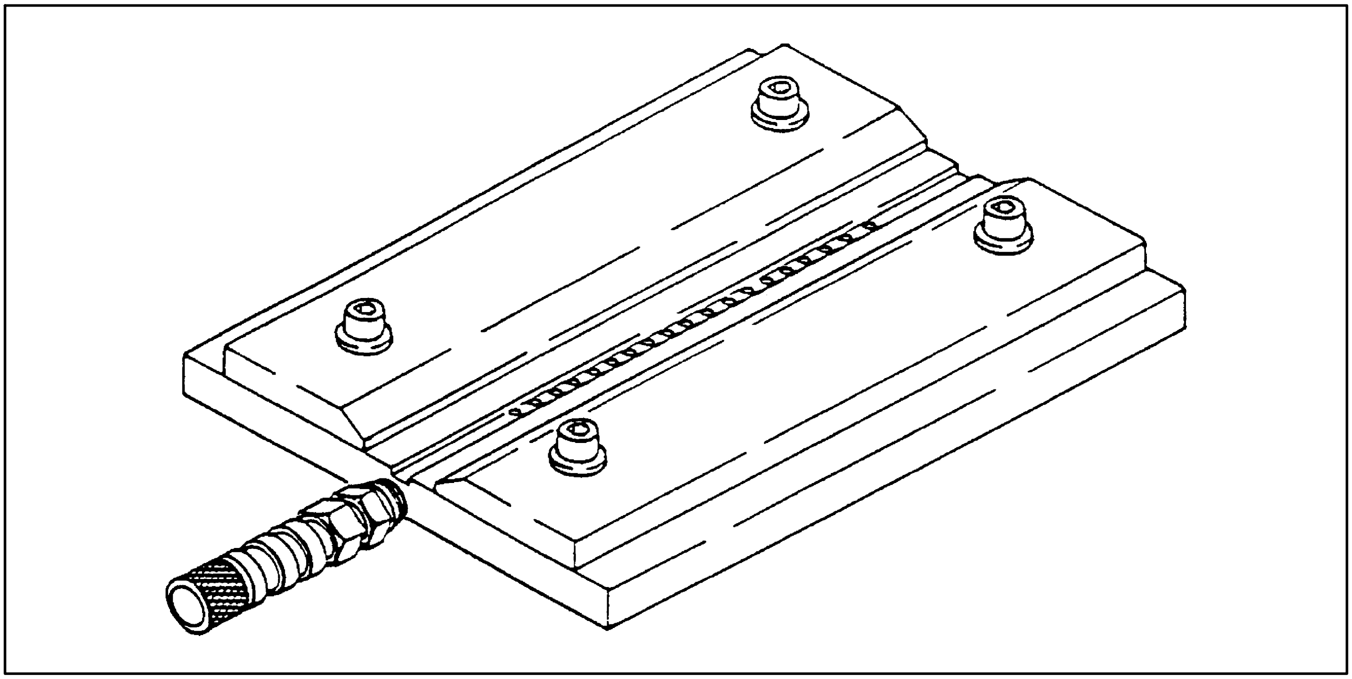


Figure 3-10. Butt Joint Welding Fixture, Pictorial (Typical)

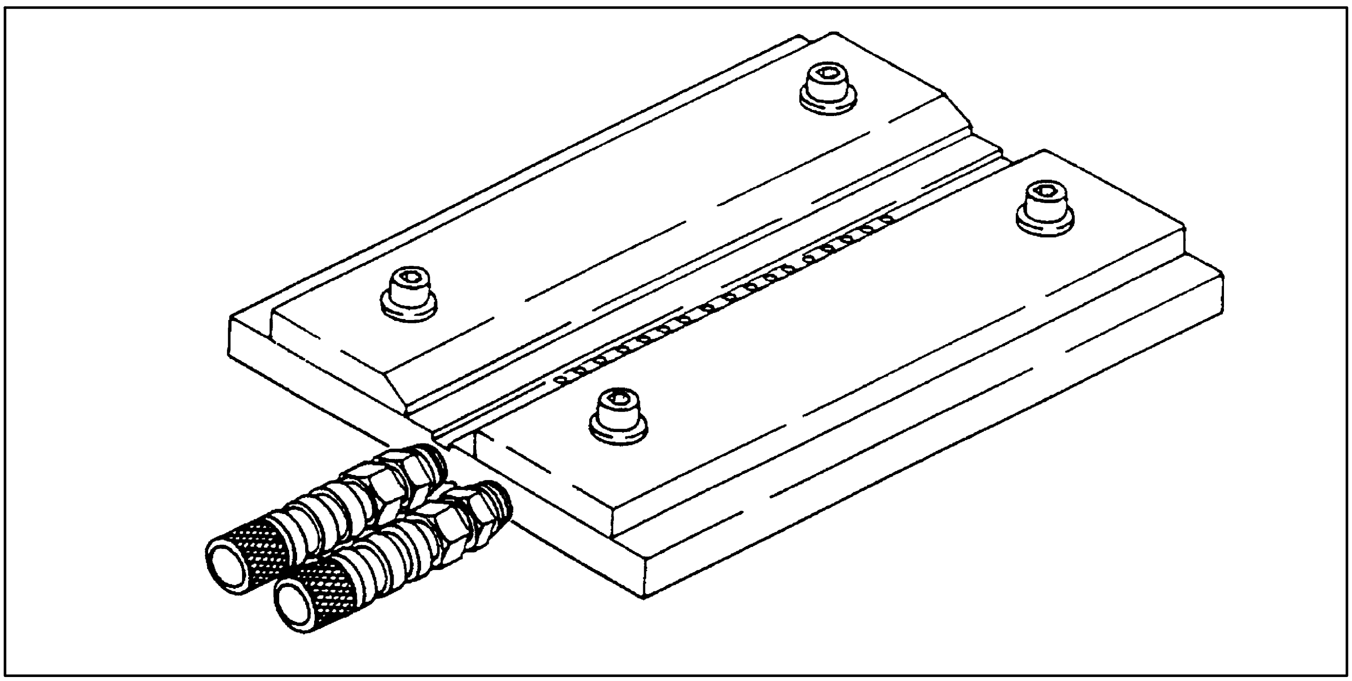


Figure 3-11. T-Joint Welding Fixture, Pictorial (Typical)

1. NAME		2. WELDING PROCESS	
3. ORGANIZATION		4. METAL GROUP	
5. DATE	6. HOURS	7. NOMENCLATURE	8. VERIFIED BY

Figure 3–12. Welder’s Log Form and Instructions (Sheet 1 of 2)

Item #1 Welder’s last name, first name and last four digits of their SSN.

Item #2 Use the initials of the welding process. Example: GTAW
See the list in paragraph 3–2

Item #3 Activity assigned to.

Item #4 Use the metal group list in Table 3–4

Item #5 Write all dates in Alpha–numeric DAY/MONTH/YEAR format, for example, 05 OCT 97

Item #6 The time the individual welded in the process and group.

Item #7 In this block the following can be entered:

a. The nomenclature/part number of the item/part

b. Proficiency Training

c. QA Verification

Item #8 Signed by the work center supervisor. The work center supervisor’s welding log will be signed/stamped by QA. See paragraph 3–17.3.1

NOTE: A separate form will be used for each metal group and process.

Figure 3–12. Welder’s Log Form and Instructions (Sheet 2 of 2)

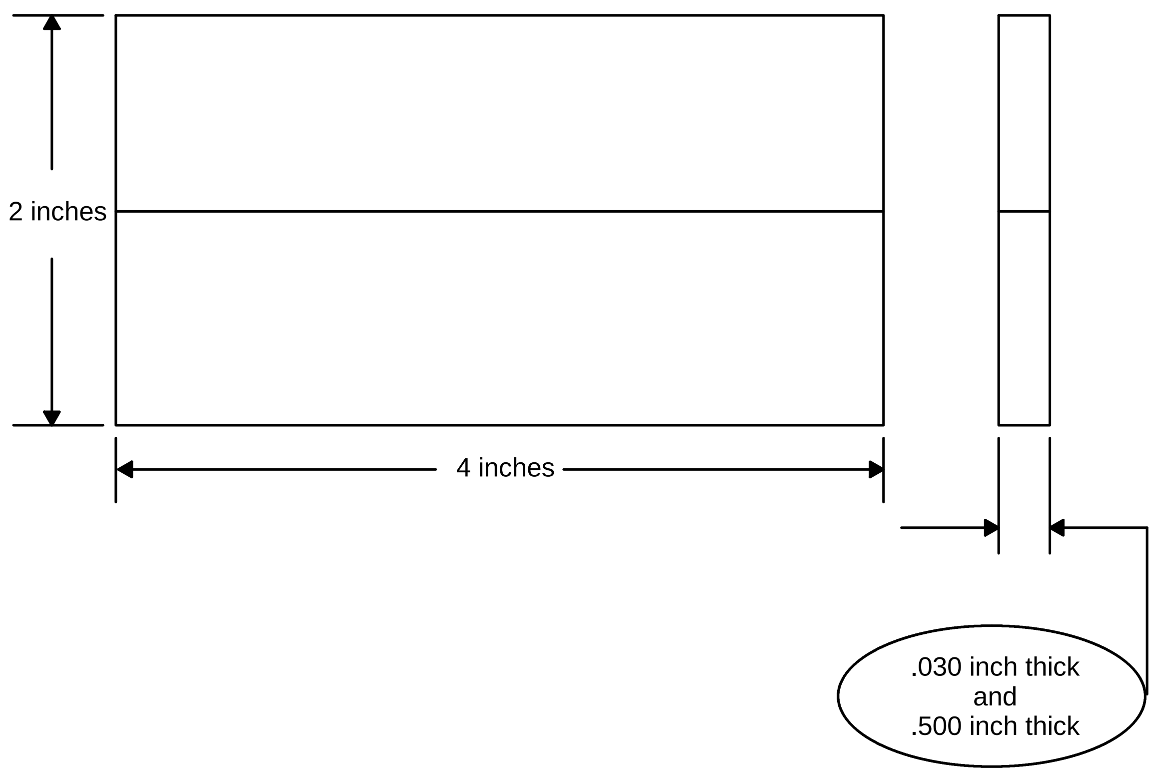
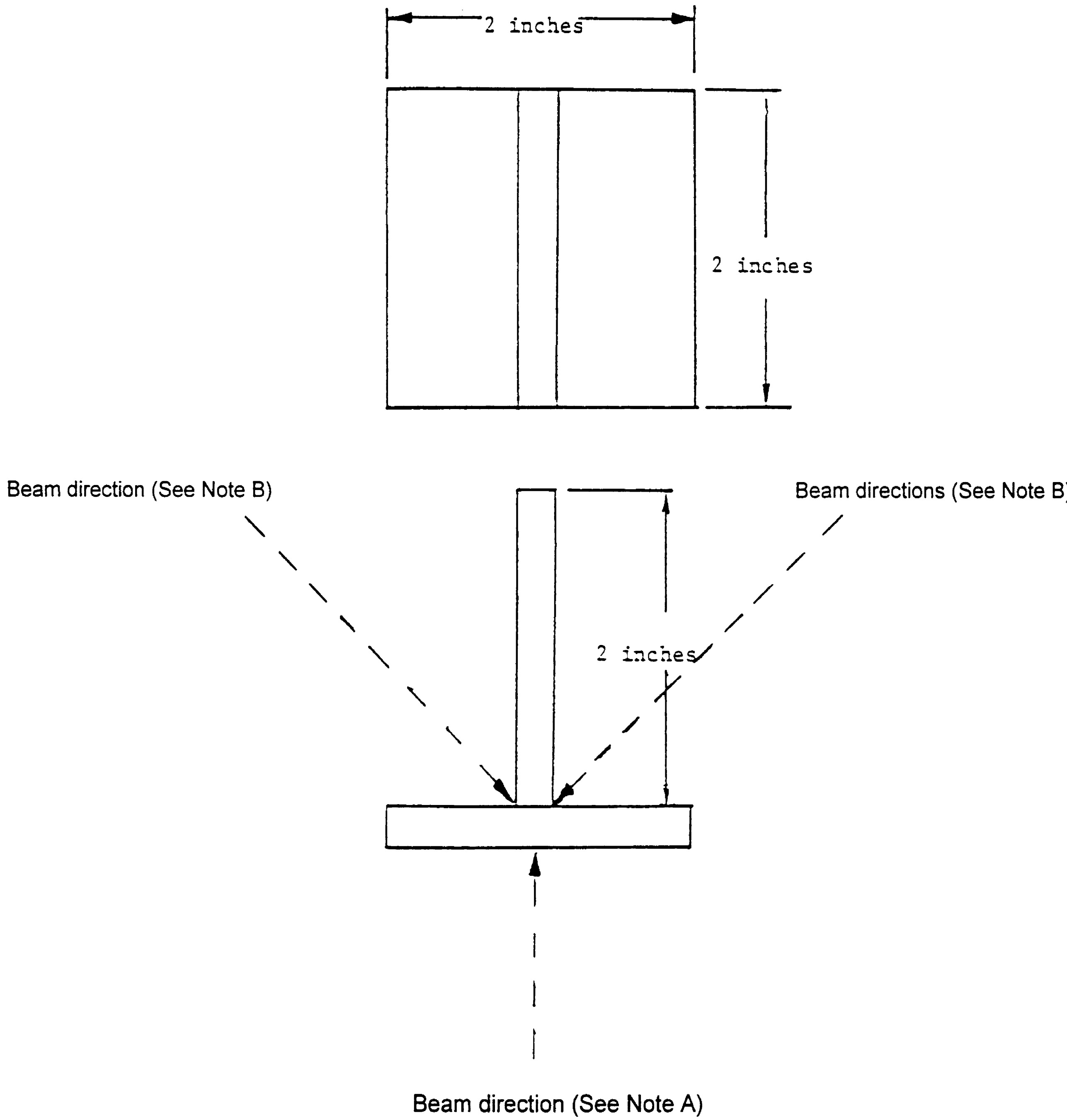


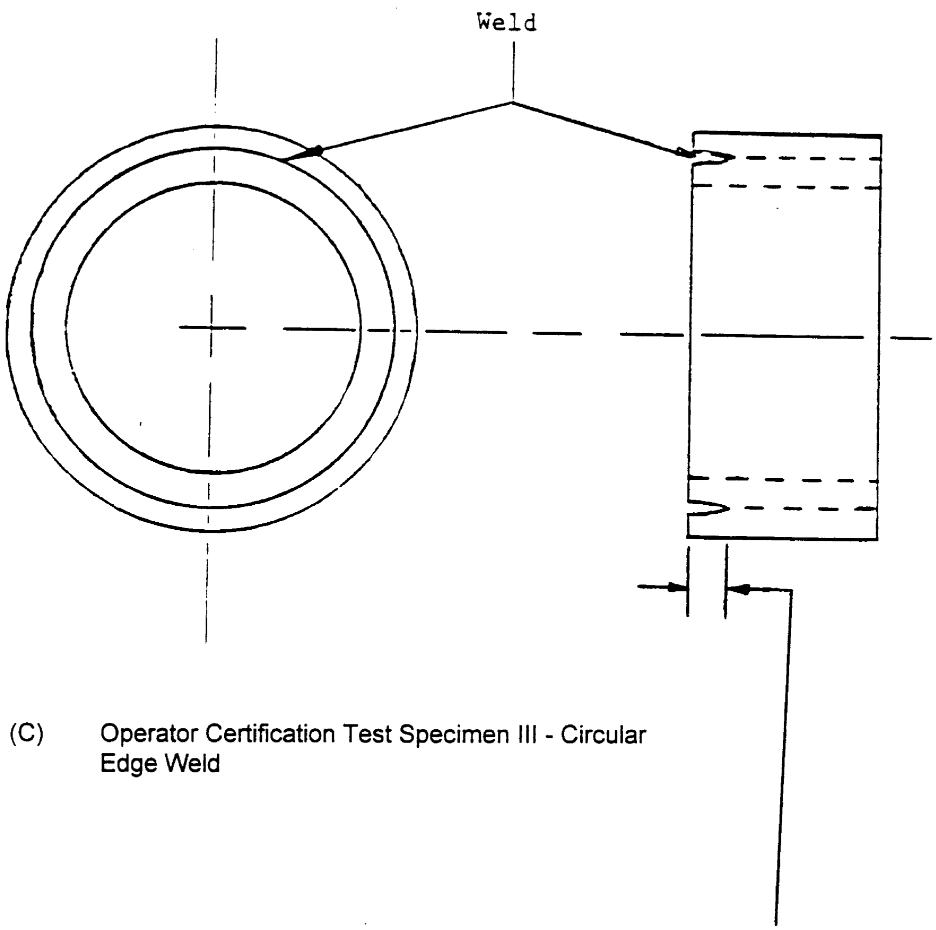
Figure 3-13. Butt Weld Specimen (Electron Beam Welding)



Note A: Joint shall be welded from backside using a .250 inch material.

Note B: Joint shall be welded into the root of the joint using .250 inch material.

Figure 3-14. T-Joint Specimen (Electron Beam Welding)



(C) Operator Certification Test Specimen III - Circular Edge Weld

Weld penetration to be equal to or greater than wall thickness

Note: Test specimens shall be manufactured as a matched set with a maximum radial clearance of .002 inch. Diameters of cylinders shall be 2 inches. Wall thickness shall be .125 inch.

Figure 3-15. Circular Edge Weld Specimen (Electron Beam Welding)

Date

Company Address

Machine Make Serial No. KVA

Mfg. of Control Panel Control Mfg.'s Type No.

WELDING DATA

SURFACE PREPARATION

Sheet Combinations	Upper	Upper	Material
			Thickness
			Condition
		Lower	Material
			Thickness
			Condition
Electrode Contour Sketch & Dimensions		Electrodes	Diameter, Upper-Lower
			Contour
			Material
			Speed (in./min.)
			Weld Force, lb.

Electrode Cooling

Distance Between Arms

Throat Depth

Power Supply Frequency

Primary Voltage

Spot Spacing

Other control settings as required for particular type machine

NOTE: All machine settings adjustable or adjusted to accomplish welding shall be recorded.

Machine Operator's Signature

Authorized Inspector's Signature

Welding Supervisor's Signature

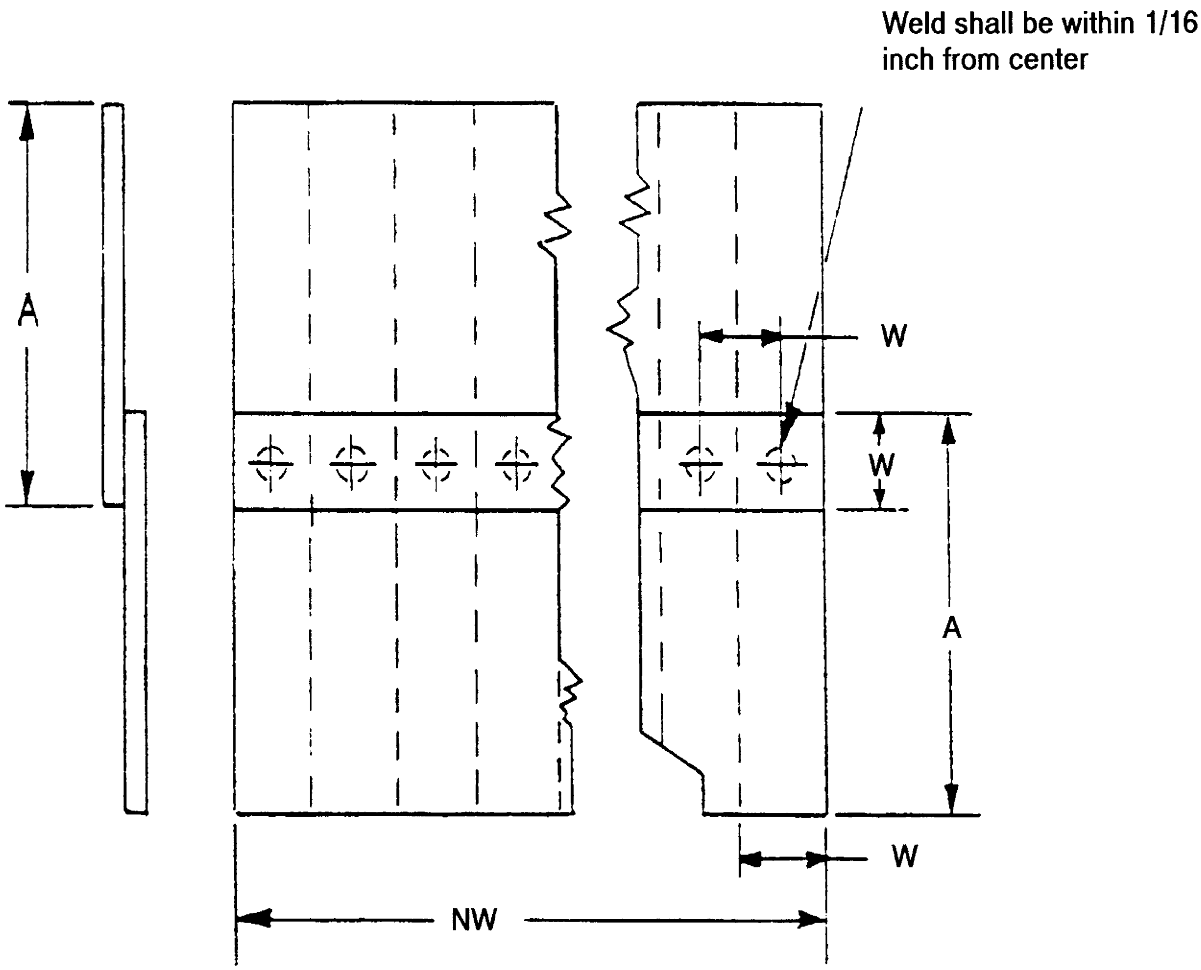
METALLURGICAL TEST REPORT OF SEAM WELD SPECIMENS

Etching Test

TEST RESULTS			Is Appearance of Weld Satisfactory?	Do Fusion Areas Overlap?	Depth of Penetration Max	Depth of Penetration Min	Defects
	Longitudinal Sections	1					
		2					
		3					
		4					
	Transverse Sections	1					
		2					
		3					
		4					

(Laboratory Director's Signature) (Authorized Inspector's Signature)

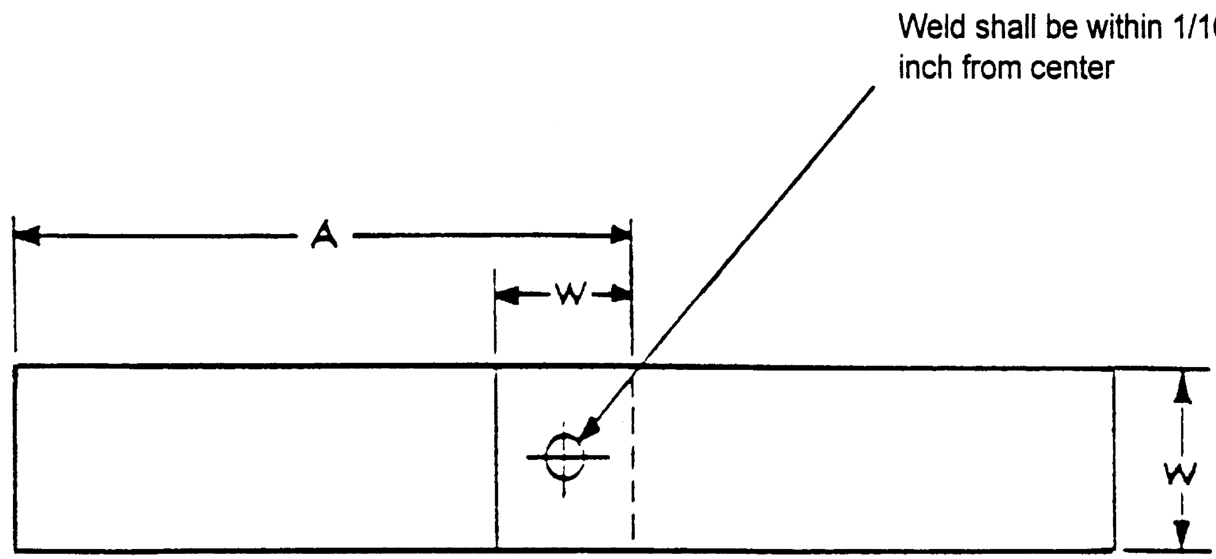
Figure 3-16. Machine Qualification Data - Suggested Report B
(To be accompanied by welding schedule)



Values for W and A are shown in Table 3-8.

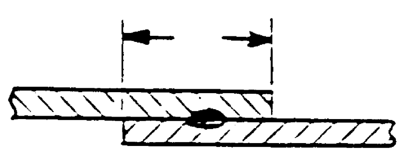
N = Number of spot welds as specified in the applicable paragraphs of the specification. The number of spot welds per set shall be not less than 30.

Figure 3–17. Multiple_Spot Shear Specimen (to be cut after welding) (Sheet 1 of 2)



Values for W and A are shown in Table 3–8.

Figure 3–17. Multiple Spot Shear Specimen (to be cut after welding) (Sheet 2 of 2)



The required overlap (W) shall be maintained as specified in Table 3–8.

Figure 3–18. Production Quality Control Shear Test Specimen (2 thicknesses)

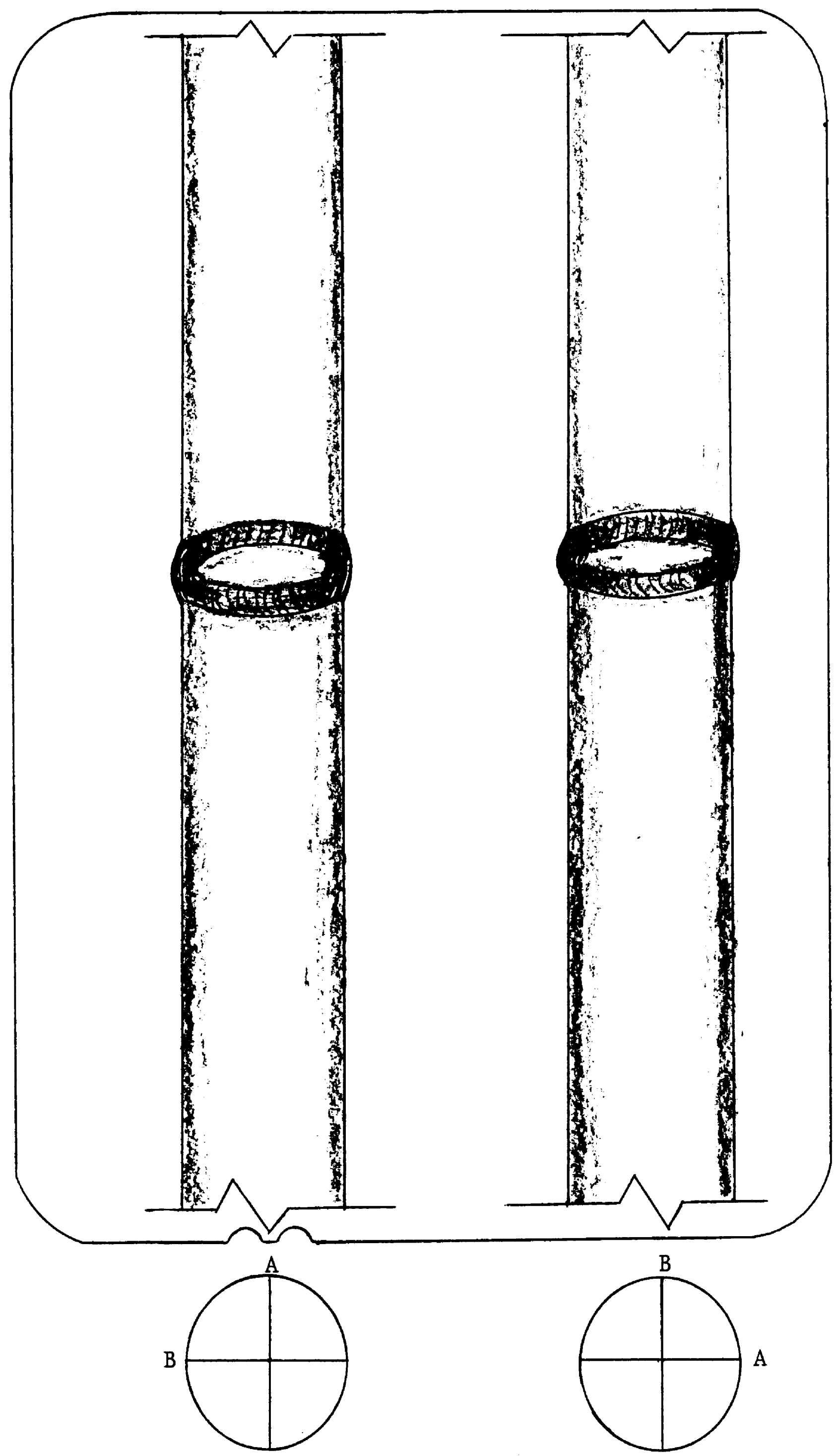


Figure 3–19. Location of Tube Film for Each Shot
Between shots tube is rotated 90_ and the film is indexed about 2.5” beneath the tube

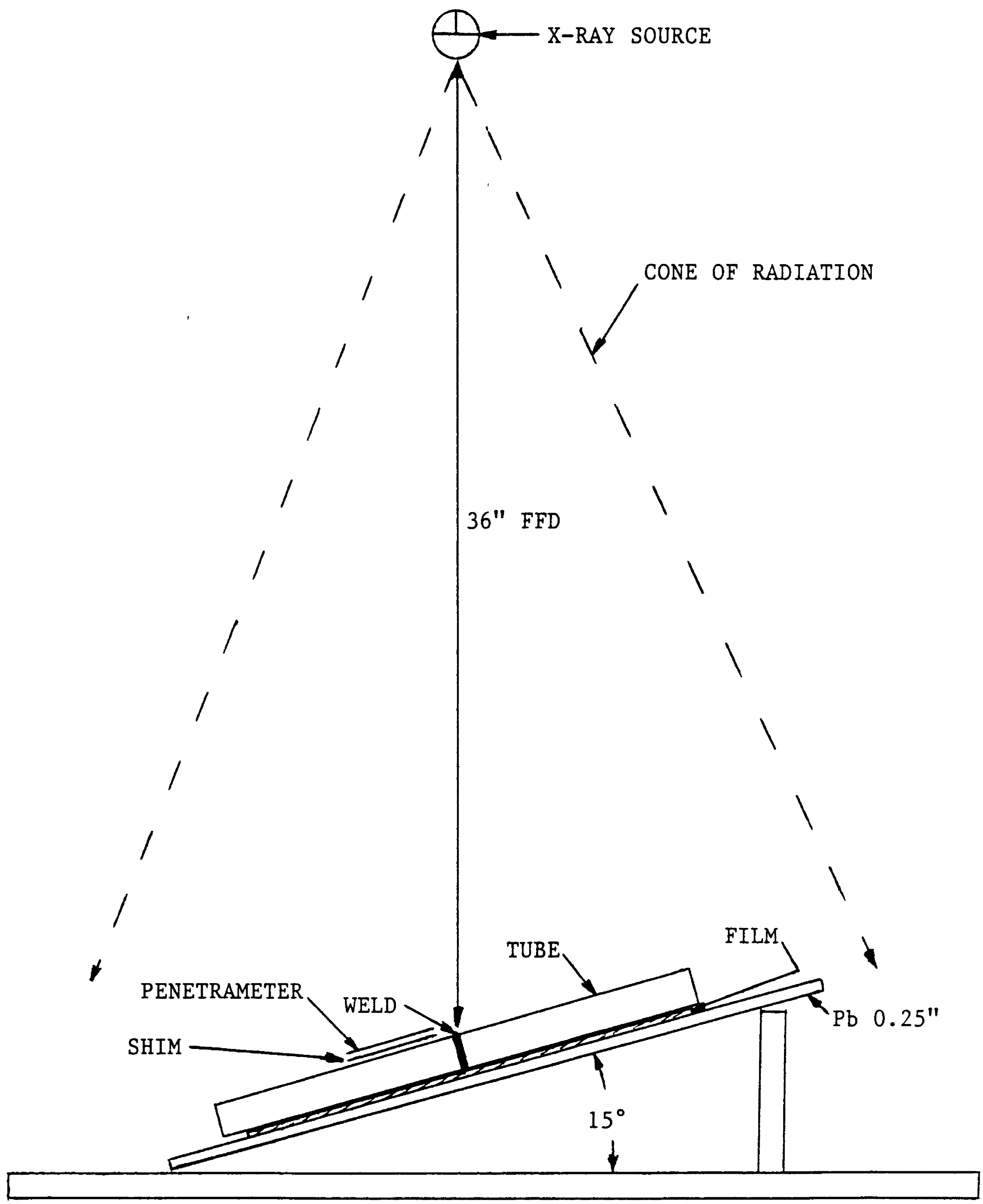


Figure 3-20. Exposure Setup - 1" tube (Sheet 1 of 2)

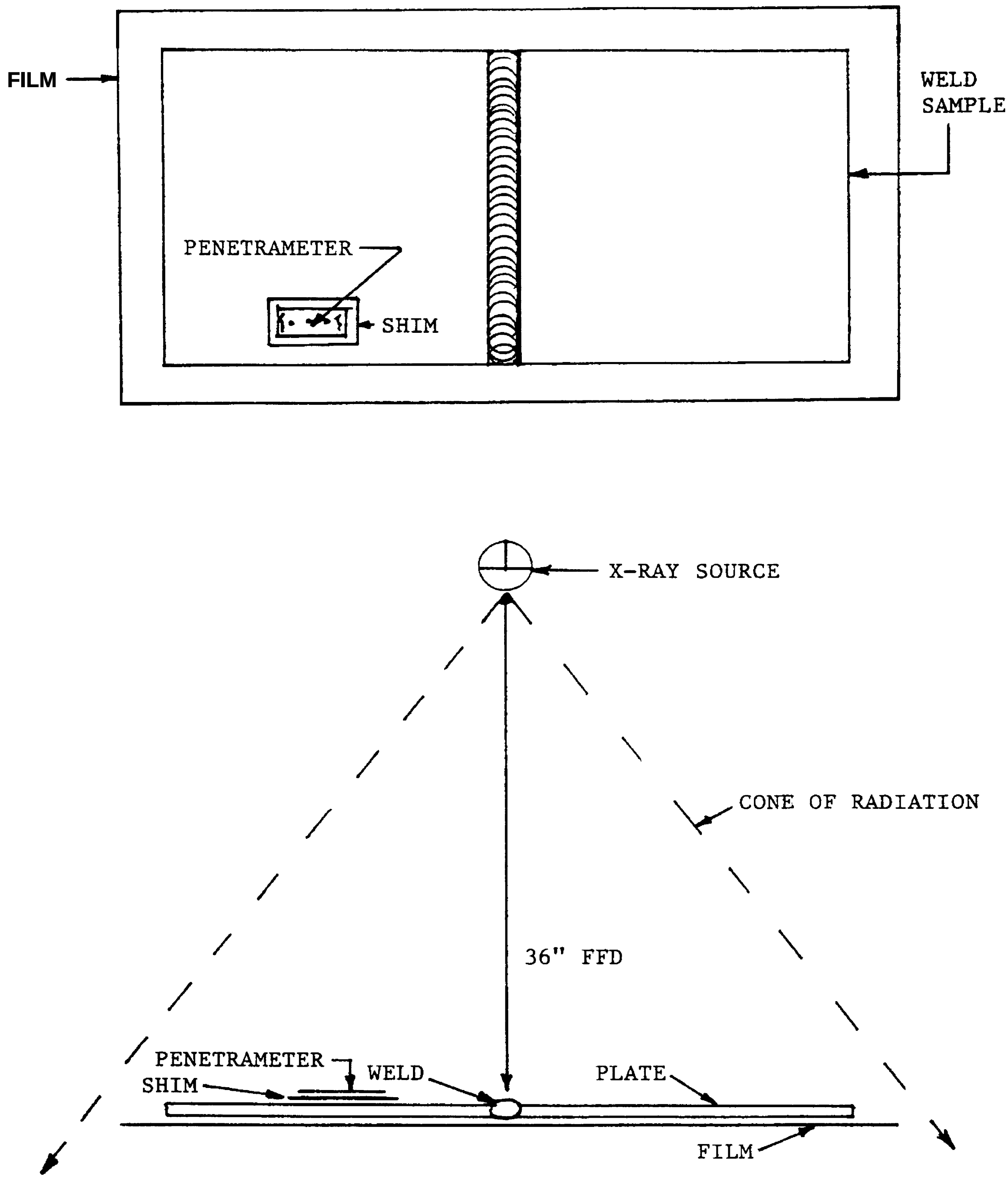


Figure 3-20. Exposure Setup – 1" tube (Sheet 2 of 2)

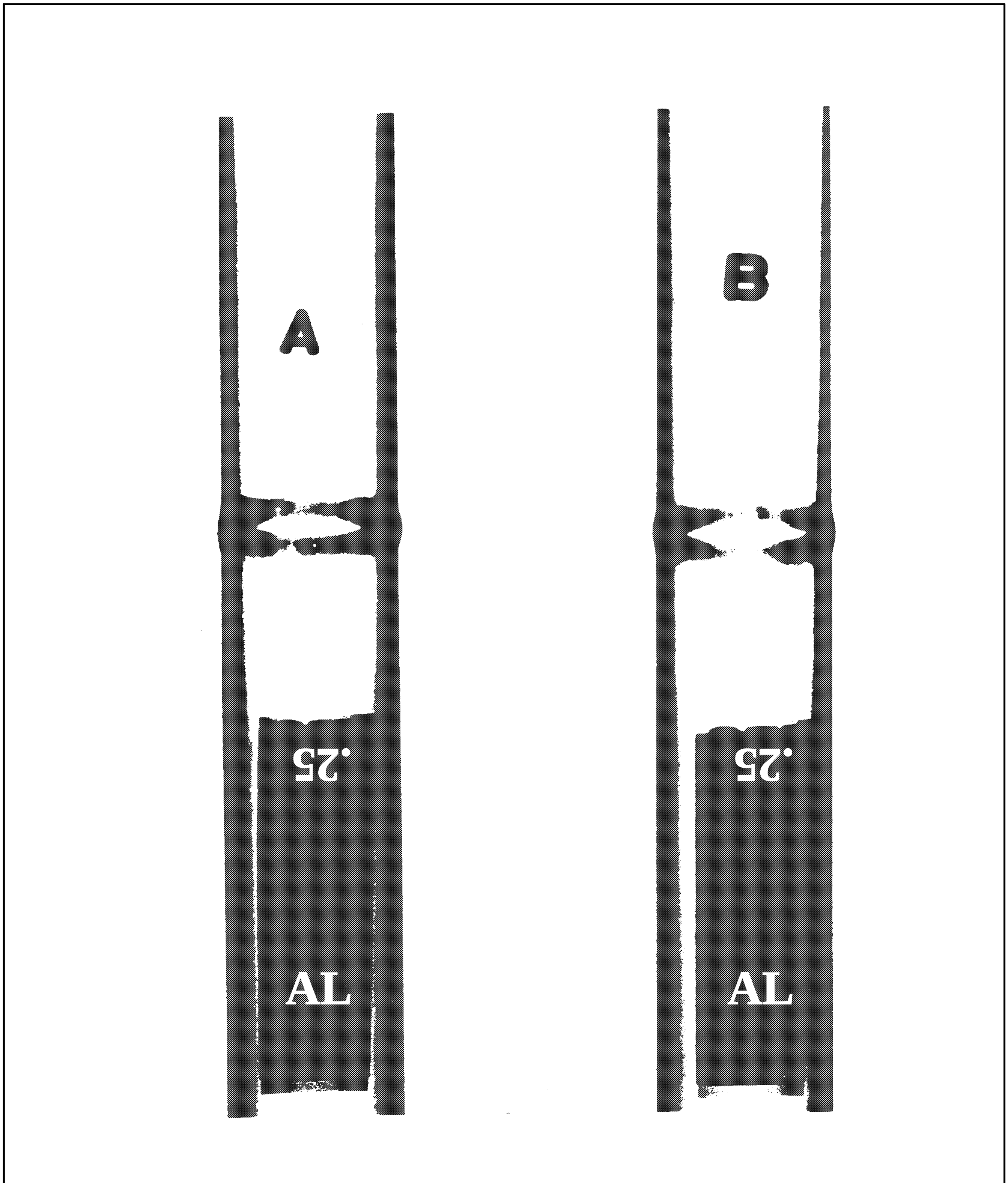
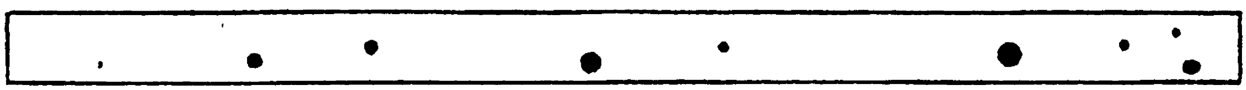
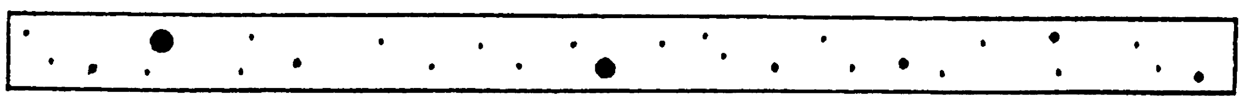


Figure 3–21. Typical Layout of Radigraphic Image



b. Base metal thickness: 0.063 inch
Represents 2 inches of weld length at 3X magnification



d. Base metal thickness: 0.250 inch
Represents 6 inches of weld length at no magnification

Figure 3–22. Allowable Maximum Total Porosity Area and Maximum Pore Size

i. Recertification course listed in Table 3–5 and the CANTRAC provides refresher training, testing and certification for IMA welders to MIL–STD–1595 for electric arc and inert gas welding. Refresher training, testing and certification for IMA torch brazers to MIL–STD–248 may be accomplished through the course listed in Table 3–5 and the CANTRAC.

j. An IMA welder will have his/her certification suspended if conditions in paragraph 3.17.4 apply.

NOTE

Suspension will be by process and metal group. Suspensions of a particular process and metal group does not revoke or suspend the welder's entire certification.

3.17.6 Recertification for individuals under paragraph 3.17.5.j will:

a. Recertify by attending depot training or

b. Recertify by submitting test specimens to one of the facilities listed in Table 3–6.

3.17.7 Prior to submission of test specimen the welder must practice the particular process and metal group and document in accordance with paragraph 3.17.3 Test specimens shall be locally inspected in accordance with this publication (visual and NDI) prior to submission.

3.17.8 Successful completion of test specimen will reinstate recertification of the welder to the initial certification.

a. Physical requirements. Refer to paragraph 3.4.1 and to OPNAVINST 5100.23.

b. Upon receipt of the completed/welded specimens and within 10 working days, the training coordinator at the depot will prepare the necessary work order paperwork, process the specimens for testing at the NDI and materials labs, obtain and report the results to the welder's activity. For overseas, activities and ships notification will be by message with the appropriate documentation to follow.

NOTE

All test plates received by the evaluation facility shall be in the as–welded condition. Any wire brushing, grinding or other cosmetic operations will be cause for specimen rejection.

3.18 <u>ARMY AVIATION UNIQUE CERTIFICATION REQUIREMENTS.</u>

Army aviation has specific, established procedures and requirements that differ from the USN and USAF and are as follows:

a. The Army aviation welders utilize both Navy, Air Force and Army schools and requirements. Army aviation welders shall certify in accordance with this section of this manual.

b. Certification Procedures. Use the forms described in Figure 3–3 to document the certification process for each welder. Figure 3–3 is the standard form issued by the designated welding certification laboratory that authorizes the individual certification. Figure 3–4 represents the personnel certification card that is issued to all Army, Navy and Air Force Aviation Certified Welders.

3.19 <u>MACHINE WELDING CERTIFICATION REQUIREMENTS.</u>

Machine welding processes include, but are not limited to electron beam welding, resistance welding and dabber TIG. Machine welder operators do not have to be certified welders. The certification usually applies to very specific or limited production parts. The certification is limited to the welding conditions of the test weld with regard to welding process, base metal composition, thickness, welding position, base metal form type of weld and other welding conditions.

3.20 <u>CERTIFICATION PROCEDURE FOR ELECTRON BEAM WELDING MACHINE OPERATORS.</u>

Certification of electron beam weld operators shall consist of: verification of the operator's ability to set up the part to be welded so that precise, accurate and repeatable welds are obtained. This test will be accomplished by using the same equipment the operator will use to produce production work.

3.20.1 <u>Certification Requirements</u>. The test shall consist of the operator setting up the equipment and welding acceptable specimens of each configuration conforming to Figures 3–13, 3–14 and 3–15. Material shall be annealed 304 stainless steel. The welds shall meet the requirement of paragraph 3.20.3b.

3.20.2 Recertification. All electron beam welders shall be re–examined every 12 months (from date of their initial certification). EB weld operators not working with the electron beam welder for a period exceeding 30 working days, shall be required to recertify per paragraph 3.17.2.

3.20.3 Weld Quality.

a. The general weld quality is as specified by individual engineering specifications governing each component weld repaired by the electron beam method.

b. Test welds will be sectioned, polished, etched and metallographically examined at 10–20X magnification. The specimens shall be sectioned at three points within the weld, at the beginning, in the center and at the end. The welds shall be uniform in appearance and have consistent penetration or drop through.

3.21 CERTIFICATION PROCEDURE FOR RESISTANCE WELDING MACHINE OPERATORS.

3.21.1 General. All resistance welding machines shall be run by certified operators only, or by a resistance welding trainee under direct supervision of a certified operator. No production welding of any nature may be performed except by a certified operator.

3.21.2 Length of Certification. Resistance welding (spot, intermittent spot and seam) operators shall be certified and recertified at intervals not to exceed one year. A 30 day extension may be authorized by the local depot engineering laboratory under certain circumstances including time for a trainee who has failed the certification test to reapply for a second examination.

NOTE

When a certified operator has not welded for a period exceeding 3 months, recertification will be required.

3.21.3 Pre–Certification Training. The resistance welding trainee will be required to serve a 3 month apprenticeship immediately prior to the certification test.

3.21.4 Scope of Training. The trainee, under the direct guidance of a certified resistance welding operator, will be required to be thoroughly familiar with the following:

a. Spot and seam welding machine controls and performance.

b. Electrode classes, sizes, contours, installation and cleaning and electrode force gage.

c. Spot and seam welding machine qualification data procedures.

d. Spot and seam welding schedule certifications.

e. Preparation and evaluation of metallographic test samples.

f. Testing of tensile and shear test coupons.

g. Evaluation of external and internal weld defects.

h. Familiarization with radiographic appearance of welds.

i. Defect limits for Class A and B welds (see Table 3–7).

j. Familiarity with any local engineering document on resistance welding. (Copy to each trainee).

k. Cleaning procedures and surface resistance measurements for aluminum and magnesium alloys.

l. Dimensions of Shear Test Specimens: (See Table 3–8).

2014–T3; equal thicknesses
304/or 321; unequal thicknesses
TI (AMS 4901); equal thicknesses

3.21.5 Responsibilities and Records.

a. The welding supervisor will be responsible for the training, examination and coordination with representatives from the local depot materials engineering laboratory.

b. The representative of Quality Assurance will supervise the test welding and associated paperwork.

c. Weld test and examination requirements are per Table 3–7, Class A, material groups (a), (b) and (c).

d. Quality Assurance will issue a personnel certification sheet to each certified resistance welding operator.

Table 3–7. Test Specimens Required for Certification Tests

Class of Weld	Weld Method	Material			
		Group (a) Materials		Group (b) & (c) Materials	
		Ultimate shear strength or pressure test specimen	Metallurgical or peel specimen[2]	Ultimate shear strength or pressure test specimen	Metallurgical or peel specimen[2]
A	Spot weld[1,5]	20 shear	5 welds microsection	10 shear	3 microsection
		10 shear	5 weld macrosection	5 shear	3 macrosection
A B	Seam weld[4]	None required	12 inches of weld	None required	12 inches of weld
A	Intermittent spot weld[3]	10 nugget diameter measurements	20 welds (10 micro-sectioned) see Figure 3–18	10 nugget diameter measurements	20 welds (10 mi-crosectioned) see Figure 3–18
		5 nugget diameter measurements	10 welds (5 macrosec-tioned) see Figure 3–18	5 nugget diameter measurements	10 welds (5 ma-crosectioned) see Figure 3–18

[1] Total number of ultimate strength shear specimens for each class shall be multiple spot shear or single spot shear specimens conforming to Figure 3–17, Sheet 1 or Sheet 2. The multiple spot shear specimens shall be cut into single spot shear specimens conforming to Figure 3–17, Sheet 1 for testing.

[2] Metallurgical specimens shall conform to the requirements of Figure 3–18. Specimen shall be cross–sectioned polished and etched closely as possible through the center of the weld for metallurgical examinations. Microsections for Class A shall be examined at a minimum of 25X to a maximum of 40X. Macrosections for Class B if required, shall be visually examined with the naked eye or under low magnifications 9X to 10X maximum).

[3] Nugget diameter measurement shall be obtained from the metallurgical specimens.

[4] Seam welds may be accomplished by the overlapping of spot welds with fixed–type electrodes when so permitted on the engineering drawing or other applicable documents. Parts, seam welded in this manner, shall be certified and controlled in accordance with seam–welding requirements.

[5] Spot welds spaced less than 2 diameters apart utilizing fixed–type electrodes shall be certified and controlled in accordance with intermittent spot welding requirements.

Table 3–8. Dimensions of Shear Test Specimen in Inches

Nominal Thickness of Thinner Sheets	OVERLAP (W) (Minimum)		Recommended Length (A)
	Group (a) [1] Materials	Group (b) [2] and (c) [3] Materials	
0.009 to 0.030	5/8	5/8	3
0.031 to 0.050	3/4	1	3
0.051 to 0.100	1	1	3
0.101 to 0.130	1 1/4	1 1/4	3
0.131 and over	1 1/2	1 1/4	3

[1] Refer to Table 3–9 for Group (a) materials.
[2] Refer to Table 3–10 for Group (b) materials.
[3] Refer to Table 3–11 for Group (c) materials.

3.22 EVALUATION.

3.22.1 General. This section provides methods, procedures and acceptance criteria for evaluation of welding qualification test welds. The test weld shall be subjected to the examination and testing methods as indicated in Table 3–12. If the base metal of a test weld is a substitution for those specific base metals given in the Welding Procedure Specifications (WPS), written authority to use that metal substitution from the cognizant material/metallurgical or welding engineer is required.

3.22.2 Visual Examination Based on MIL–STD–1595. The length of weld to be examined shall be the entire circumference of all joints. Visual examination shall be at a magnification of 3X for WPS 1 through 7, 9, 11 through 26; but magnification is not required for WPS 8 and 10. All welds will be evaluated in the as–welded condition. Grinding, wire brushing, filing, and any other cosmetic modification will be cause for specimen rejection.

3.22.3 Groove welds. Groove welds in tube of material thickness □ 0.050 which have any of the following defects are unacceptable:

a. Any type of crack.

Table 3–9. Minimum required shear strength per weld for spot weld shear specimens and minimum average strength [1]

Nominal thickness of thinner sheet (inch)	Group (a) Materials							
	Ultimate strength 56,000 psi & above(A)		Ultimate strength 35,000 to 55,999 psi (B)		Ultimate strength 19,500 to 34,999 psi (C)		Ultimate strength below 19,500 psi (D)	
	Pounds Per Weld							
Thickness [2]	Minimum	Minimum Average	Minimum	Minimum Average	Minimum	Minimum Average	Minimum	Minimum Average
0.010	60	75	50	65	––	––	––	––
0.012	75	95	65	85	30	40	20	25
0.016	110	140	100	125	70	90	50	65
0.018	125	160	115	145	85	110	65	85
0.020	140	175	135	170	100	125	80	100
0.022	160	200	155	195	120	150	95	120
0.025	185	235	175	200	145	185	110	140
0.028	215	270	205	260	175	220	135	170
0.032	260	325	235	295	210	265	165	210
0.036	305	385	275	345	255	320	195	245
0.040	345	435	310	390	300	375	225	285
0.045	405	510	370	465	350	440	260	325
0.050	465	585	430	540	400	500	295	370
0.056	555	670	515	645	475	595	340	425
0.063	670	840	610	75	570	715	395	495
0.071	825	1035	720	900	645	810	450	565
0.080	1025	1285	855	1070	765	960	525	660
0.090	1255	1570	1000	1250	870	1090	595	745
0.100	1490	1865	1170	1465	940	1175	675	845
0.112	1780	2225	1340	1675	1000	1255	735	920
0.125	2120	2650	1625	2035	1050	1315	785	985
0.140	2525	3160	1920	2400	––	––	––	––
0.160	3120	3900	2440	3050	––	––	––	––
0.180	3725	4660	3000	3750	––	––	––	––
0.190	4035	5045	3240	4050	––	––	––	––
0.250	7350	9200	6400	8000	––	––	––	––

[1] Strength of material shall be based on its guaranteed minimum ultimate tensile strength. In the case of "0" temper materials, the maximum tensile shall apply.

[2] Standard MIL–STD–204 may be used as an alternate. Interpolation can be used to establish strength values.

ALLOYS

A	B	C	D
2014–T3, –T4, –T6, –T651, –T62	2017–T4	1100–H16, –H18	1100–H12, –H14
2024–T3, –T351, –T36, –T4, –T42, –T6, –T62, –T81, –T851, –T86	2219–T31, –T62, –T6	3003–H14, –H16, –H18	3003–H12
2219–T81, –T851, –T87	5052–H36, –H38	5052–H32, –H34	
7075–T6, –T651, –T73	6061–T6, –T651	6061–T4	
7079–T6, –T652	6062–T6, –T651	6061–T4	
7178–T6, –T651			

Table 3–10. Minimum required shear strength per weld and minimum average strength for spot weld shear specimens

Nominal thickness of thinner sheet (inch)	Group (b) Materials[1]							
	Ultimate strength above 185,000 psi (A)		Ultimate strength 150,000 to 185,000 psi (B)		Ultimate strength 90,000 to 149,999 psi (C)		Ultimate strength below 90,000 psi (D)	
	Pounds Per Weld							
Thickness [2]	Minimum	Minimum Average	Minimum	Minimum Average	Minimum	Minimum Average	Minimum	Minimum Average
0.009	200	245	175	210	130	160	100	125
0.010	245	305	205	255	160	195	115	140
0.012	350	410	275	340	200	245	150	185
0.016	480	595	400	495	295	365	215	260
0.018	590	725	490	600	340	415	250	305
0.020	635	785	530	655	390	480	280	345
0.022	730	905	610	755	450	550	330	405
0.025	870	1075	725	895	530	655	400	495
0.028	1025	1260	855	1055	635	785	465	575
0.032	1250	1545	1045	1280	775	955	565	695
0.036	1500	1850	1255	1545	920	1140	690	860
0.040	1750	2150	1460	1800	1065	1310	815	1000
0.045	2100	2600	1795	2210	1285	1585	1005	1240
0.050	2450	3000	2125	2620	1505	1855	1195	1475
0.056	2880	3550	2550	3145	1770	2185	1460	1800
0.063	3550	4375	3090	3815	2110	2595	1760	2170
0.071	4200	5150	3730	4595	2535	3125	2080	2560
0.080	4850	6000	4410	5440	3005	3705	2455	3025
0.090	5600	6900	5090	6275	3515	4335	2885	3560
0.100	6300	7750	5720	7050	4000	4935	3300	4070
0.112	7000	8600	6395	7855	4545	5610	3795	4675
0.125	7785	9600	7080	8730	5065	6250	4300	5310

[1] Strength of material shall be based on its guaranteed minimum ultimate tensile strength.
[2] Interpolation can be used to establish strength values.

ALLOYS

A	B	C	D
301–H PH15–7MO (RH950)	301–1/2H, –3/4H 321–1/2, –3/4H 17–7PH (TH1050), (RH950) PH15–7MO (TH–1050) Inconel X750 – Aged Rene 41 – Solution or Aged	301–1/4H 321–1/4H 19–9DL – Ann 19–9DX – Ann Hastelloy X – Ann Inconel X750 – Ann L605 – Ann A–286 – Hardened Inco 718 – Ann Inco 625 – Ann	Low carbon steel Annealed Monel Inconel 301, 302, 304, 310, 316, 321, 347 A–286

Strengh of quench hardenable steels will depend on tempering temperature. Consult local metallurgical lab, for other alloys.

Table 3–11. Minimum required shear strength per weld for spot weld shear specimens and minimum average strength[1]

Nominal thickness of thinner sheet (inch)	Group (c) Materials			
	Ultimate strength above 100,000 psi (A)		Ultimate strength 100,000 psi or below (B)	
	Pounds Per Weld			
Thickness [2]	Minimum	Minimum Average	Minimum	Minimum Average
0.010	60	75	50	65
0.012	75	95	65	85
0.016	110	140	100	125
0.018	125	160	115	145
0.020	140	175	135	170
0.022	160	200	155	195
0.025	185	235	175	200
0.028	215	270	205	260
0.032	260	325	235	295
0.036	305	385	275	345
0.040	345	435	310	390
0.045	405	510	370	465
0.050	465	585	430	540
0.056	555	670	515	645
0.063	670	840	610	75
0.071	825	1035	720	900
0.080	1025	1285	855	1070
0.090	1255	1570	1000	1250
0.100	1490	1865	1170	1465
0.112	1780	2225	1340	1675
0.125	2120	2650	1625	2035
0.140	2525	3160	1920	2400
0.160	3120	3900	2440	3050
0.180	3725	4660	3000	3750
0.190	4035	5045	3240	4050
0.250	7350	9200	6400	8000

[1] Strength of material shall be based on its guaranteed minimum ultimate tensile strength. In the case of “0” temper materials, the maximum tensile shall apply.

[2] Standard MIL–STD–204 may be used as an alternate. Interpolation can be used to establish strength values.

ALLOYS

A Alloys	B Alloys
Ti–5Al–2 1/2Sn Ti–8Al–1Mo–1V Ti–6Al–4V Ti–6Al–6V–2Sn	Unalloyed Ti such as AMS 4901 Ti – 8 Mn <u>not</u> weldable

Table 3–12. Required Examination and Testing by Metal Group (from Table 3–3)

WPS NO.	VISUAL	RADIOGRAPHIC
1–26	ALL	ALL
NOTE: All tubing and pipe less than 0.250” wall thickness does not require metallographic or bend testing.		

b. Incomplete joint penetration (i.e. there shall be measurable root and face reinforcement apparent).

c. Underfill.

d. Overlap.

e. For test welds with a base metal thickness of more than 0.050”, undercut at any location in excess of 10% or 0.032”, whichever is the lesser.

f. Mismatch at any location in excess of 10% of the base metal thickness or 0.12”, whichever is the lesser, except that a mismatch up to 25% is allowed for a base metal thickness of equal to or less than 0.063”.

g. Reinforcement of the weld face or the weld root in excess of that shown in Table 3–14.

h. After radiographic inspection, section all tubes longitudinally to inspect penetration.

3.23 RADIOGRAPHIC INSPECTION OF TUBE BUTT JOINTS FOR THE PURPOSES OF WELDER CERTIFICATION.

3.23.1 General. Radiograph inspection shall be performed in accordance with MIL–STD–453, NA 01–1A–16 and T.O. 33B–1–1.

3.23.2 Part Preparation. Wipe inspection area with an approved solvent.

WARNING

X–ray radiation is harmful to personnel. Consult bioenvironmental office for the required radiation protection for this equipment.

WARNING

RADIATION HAZARD

Ensure compliance with all applicable safety precautions set forth in T.O. 33B–1–1. Failure to comply may result in injury to personnel.

3.23.3 Inspection Equipment and Materials.

a. A 150 KVP radiographic x–ray apparatus or equivalent with a beryllium window.

b. Penetrameter for material (MIL–STD–453). See Table 3–13.

c. Shims equaling thickness of weld build–up on one wall of tube (see Table 3–13).

d. Lead identification materials.

e. Lead cover plates are needed if multiple shots are to appear on one sheet of film. Recommend two plates, each 8” x 8” x 0.25”.

f. Film badge.

g. Two pocket dosimeters.

h. Radiation survey meter.

i. Eastman Kodak Co. Industrex Type M–8 Ready Pack and Lead Pack film, or equivalent. Sheets of film 5” x 7” are preferred.

j. Eastman Kodak Co. X–OMAT Model B film processor, or equivalent.

3.23.4 Safety. Check that the radiation survey meter is operational and aim it toward the tube head. Set the survey meter for maximum sensitivity.

3.23.5 Inspection Setup.

a. Turn on x–ray system.

b. Consult equipment manuals for proper warm–up procedures.

c. Mark 1.0” tube circumference for double wall inspection in two shots, each centered 90_ from the previous (see Figure 3–20). Butt joint sheets are shot in a single shot.

Table 3-13. Recommended Inspection Settings

MATERIAL	MATERIAL THICKNESS	KV/MAM[1]	IQI[2]	SHIM	FILM
Steel Tube	1.0”/0.050” thick tube	120/16.9	FE .25	0.032	5 x 7 M-8Pb
Stainless Steel Tube	1.0”/0.050” thick tube	120/16.9	SS .25	0.032	5 x 7 M-8Pb
Inconel Tube	1.0”/0.050” thick tube	130/16.9	IN .25	0.032	5 x 7 M-8Pb
Aluminum Tube	1.0”/0.050” thick tube	50/16.9	AL .25	0.062	5 x 7 M-8
Magnesium Tube	1.0”/0.050” thick tube	40/22.5	MG .25	0.062	5 x 7 M-8
Titanium Tube	1.0”/0.050” thick tube	90/16.9	TI .25	0.032	5 x 7 M-8
Cobalt Tube	1.0”/0.050” thick tube	140/33.8	IN .25	0.032	5 x 7 M-8Pb
Steel Sheet	0.250” thick sheet	150/50.6	FE .43	0.190	5 x 7 M-8Pb
Steel Sheet	0.032” thick sheet	120/8.3	FE .25	0.032	5 x 7 M Pb
Steel Sheet	0.125” thick sheet	120/20.0	FE .25	0.032	5 x 7 M Pb
Stainless Steel Sheet	0.020” thick sheet	120/5.8	SS .25	0.032	5 x 7 M Pb
Stainless Steel Sheet	0.032” thick sheet	120/8.3	SS .25	0.032	5 x 7 M Pb
Stainless Steel Sheet	0.125” thick sheet	120/20.0	SS .25	0.032	5 x 7 M Pb
Inconel Sheet	0.020” thick sheet	120/7.9	IN .25	0.032	5 x 7 M Pb
Inconel Sheet	0.040” thick sheet	120/11.7	IN .25	0.032	5 x 7 M Pb
Inconel Sheet	0.125” thick sheet	130/20.0	IN .25	0.032	5 x 7 M Pb
Aluminum Sheet	0.020” thick sheet	50/7.0	AL .25	-	5 x 7 M
Aluminum Sheet	0.032” thick sheet	50/10.0	AL .25	0.062	5 x 7 M
Aluminum Sheet	0.125” thick sheet	50/19.0	AL .25	0.062	5 x 7 M
Magnesium Sheet	0.032” thick sheet	40/10.0	MG .25	0.062	5 x 7 M
Magnesium Sheet	0.125” thick sheet	40/19.0	MG .25	0.062	5 x 7 M
Titanium Sheet	0.020” thick sheet	90/7.0	TI .25	0.032	5 x 7 M Pb
Titanium Sheet	0.040” thick sheet	90/11.7	TI .25	0.032	5 x 7 M Pb
Titanium Sheet	0.125” thick sheet	90/20.0	TI .25	0.032	5 x 7 M Pb
Cobalt Sheet	0.016” thick sheet	120/20.0	-	0.032	5 x 7 M Pb

[1] Milliamps per minute

[2] Image Quality Indicator

d. Use lead identification materials to identify each film to be traceable to the welder's name, date welded, joint type, base metal, inspector's name, date inspected.

e. Arrange tube head, welded sample, film, penetrameter and shims per Figure 3–20, Sheet 1 and 2.

f. For the 1.0" tube, having both shots on one sheet of film is preferred. Smaller and separate sheets of film may be used. The welded tube shall be rotated 90_ between shots. When using a single sheet of film for both shots, lead plates shall be used to cover the film, so only the area directly under the welded tube is exposed.

g. The settings shown in Table 3–13 are recommended. Deviation from these settings may be necessary to obtain the required film density and image of the penetrameter hole.

3.23.6 Film Evaluation.

a. Image quality shall be 2–1T for all exposures.

b. Film density in the penetrameter image and the weld fusion zone shall be 2.0–3.0. The film density measured from the weld shall be within 85% to 130% of the film density measured from the penetrameter. Density measurements of the penetrameter image shall be taken around the T–hole closest to the weld.

c. Compare weld defects identified on the film to radiographic requirements. The typical image will appear as shown in Figure 3–21.

3.23.7 MARKING. Identify defects on the film which are cause for rejection.

3.23.8 RECORDS. If certification is approved, radiographs shall be maintained for as long as the welder's certification is valid. If certification is disapproved, radiographs shall be maintained until individual passes certification.

3.23.9 Interpretation of Indications.

a. A linear indication is defined as one whose maximum dimension is more than three times its minimum dimension.

b. Nonlinear indications with major and minor dimensions shall be evaluated as an equivalent circle with estimated average diameter. This estimated diameter shall be the size used in determining the acceptability of the indication and the area corresponding to this estimated diameter shall be used in calculating the area of an indication.

c. Tungsten inclusions shall be counted as porosity.

d. In a test weld with a base metal thickness of equal to or less than 0.063", disregard all indications of less than 0.002 inch size. In a test weld with a base metal thickness of more than 0.063", disregard all indications of less than 0.005" or 0.02 t in size, whichever is greater.

3.23.10 Unacceptable Indications. Test welds, whose radiograph of the inspected length shows any of the following indications, are unacceptable:

a. Any type of crack.

b. Incomplete joint penetration, except as indicated in Table 3–15.

c. Internal linear indications in excess of those shown in Table 3–15.

d. Porosity in excess of that shown in Table 3–16. Examples of the allowable maximum total porosity area and the maximum pore size are shown in Figure 3–22.

Table 3-14. Weld Reinforcement Requirements by Metal Group

WPS	Metal Group	Maximum Reinforcement Allowed (Inches)	
		Face	Root
		Any Location	Any Location
1, 2, 3, 6, 7, 11, 15, 17, 24	I, II, III, VI, VII	.050	.050
4, 5	IV, V	.050	.070
8, 10	I	.20	.20
12, 16	I, III	.100	.100
18, 21	IV, V	.050	.062
19, 22	IV, V	.100	.125
14	II	.040	.040
26	VII	.036	.036
20	IV	.040	.050

Table 3-15. Maximum Linear Indications

Linear Indication	Indication Length						
	Base Metal Thickness, Inch						
	Tube .050[1]	Sheet .016	Sheet .020	Sheet .032	Sheet .040	Sheet .125	Sheet .250
Length of any indication	.100	.032	.040	.064	.080	.125	.250
Accumulated length in any 1 inch weld length	.100	.032	.040	.064	.080	.125	.250
Average length	.050	.016	.020	.032	.040	.062	.125

[1] Based on 1 inch outside diameter tubing with weld bead length of 3.14 inches

Table 3–16. Maximum Allowable Porosity

Porosity	Porosity Size, Area or Amount Base Metal Thickness						
	Tube .050[1]	Sheet .016	Sheet .020	Sheet .032	Sheet .040	Sheet .125	Sheet .250
Any Pore	.017	.005	.007	.011	.013	.041	.083
8 Pores of	.015	.005	.006	.010	.012	N/A	N/A
12 Pores of	N/A	N/A	N/A	N/A	N/A	.025	.050
Total porosity area	.005 sq. in.	.002 sq. in.	.002 sq. in.	.003 sq. in.	.004 sq. in.	0.10 sq. in.	0.10 sq. in.
Cluster porosity area in any 1/2” of weld length	.002 sq. in.	.0006 sq. in.	.0008 sq. in.	.001 sq. in.	.002 sq. in.	.003 sq. in.	.006 sq. in.
Aligned porosity area[2]	.001 sq. in.	.0003 sq. in.	.0004 sq. in.	.0006 sq. in.	.0008 sq. in.	.002 sq. in.	.004 sq. in.

[1] Based on 1 inch outside diameter tubing with weld bead length of 3.14 inches.

[2] Aligned porosity is defined as a group of more than 3 pores with 1/2” of weld length and which may be intersected by a straight line

SECTION IV.
BASE MATERIAL

4.1 GENERATION OF HEAT IN WELDING.

One BTU (British Thermal Unit) (about 252 calories) is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. The approximate heat energy required to raise the temperature of one pound of solid steel from room temperature to its melting point 2700−F (still in solid state) is 430 BTU or 109,000 calories.

4.1.1 An additional amount of heat is required to transform the solid steel to the liquid state without further increase in temperature. This heat, called the latent heat of fusion, is about 115 BTU per pound of steel. Therefore, the total heat required to melt one pound of steel is 430 plus 115: or a total of 545 BTUs.

4.1.2 In actual welding, a greater amount of heat is required to fuse a given amount of metal in a joint due to heat loss through conduction to the adjacent metal. Therefore, the heat input for welding must be sufficient to melt the metal despite the constant loss of heat to colder metal next to the weld pool and to the environment. Generally, one–fourth of the heat is lost to the air and the electrode leaving three– fourths of the heat to raise the temperature of the part to be welded.

4.1.3 The heat developed by the arc is approximately: Arc voltage times arc current times time the arc burns. An electrode arc at 35 volts, 150 amps generates 35 times 150 = 5250 watts or 5 BTU every second.

4.2 PROPERTIES OF A METAL.

There are two distinct properties of a metal. A physical property is an inherent characteristic of the metal such as melting point or magnetic property and is not dependent on external pressure or force to determine its limits if there is no physical change in the metal structure. A mechanical property, on the other hand, is measured by the extent to which the metal reacts to the applied force. For example, tensile strength of a metal is determined by how much force is applied to the metal before it breaks. For the purpose of welding, the mechanical properties of a weld are more important considerations than the physical properties.

4.2.1 Some important mechanical properties a welder should know about are:

a. Tensile Strength. Tensile strength is expressed as either TS or UTS (ultimate tensile strength) and appears in literature frequently to describe the ultimate strength where a metal will break under gradual increase of the load in longitudinal direction. Tensile strength is usually expressed in pounds per square inch (PSI) or (KSI) which is one thousand times PSI. For example, if a steel has an ultimate tensile strength of 90,000 psi or 90 KSI, a load of 90,000 pounds is required to break the steel if it has one square inch of cross sectional area. In other words, the steel will bear the load up to 89,999 pounds without failure under equilibrium conditions.

b. Yield Strength (YS). Yield strength is a stress required to produce the initial significant plastic deformation of the metal. Yield strength is usually much less than the tensile strength but is a useful mechanical property in designing the structure.

c. Fatigue Strength. Fatigue strength is the ability of a metal to withstand cyclical or repeated alternating stress without breaking. Since the aircraft landing gear is repeatedly subjected to a severe cyclical load each time it lands and takes off, fatigue strength is a very important physical property for landing gear material. Metal fatigue or fatigue failure occurs at much lower strength levels than yield or tensile strength limits.

d. Shear Strength. Shear strength is the maximum amount of cross sectional stress that a metal will sustain before permanent deformation or rupture occurs.

e. Elasticity. Elasticity is the property of a metal that allows it to be stretched like a rubber band and return to its original size and shape after load is removed. Of course, it is hard to observe the stretch by the unaided eye but with proper testing equipment, the elasticity can be demonstrated. The elastic property is very important in design considerations as a basic requisite because the metal used must return to its original shape when the load is removed.

Table 4–1. Basic Numerals of Most Commonly Used Steels

TYPES OF STEEL	NUMERALS (and digits)
CARBON STEELS	1xxx
Plain Carbon	10xx
Free Cutting (screw stock)	11xx
Manganese Steel	13xx
NICKEL CHROMIUM STEELS	3xxx
1.25% Nickel, 0.65% Chromium	31xx
MOLYBDENUM STEELS	4xxx
0.25% Molybdenum	40xx
NICKEL–CHROMIUM–MOLYBDENUM STEELS	
1.80% Nickel; 0.5% – 0.8% Chromium; 0.25% Molybdenum	43xx
0.55% Nickel; 0.50%– 0.65% Chromium; 0.20% Molybdenum	86xx
0.55% Nickel; 0.50% Chromium; 0.25% Molybdenum	87xx
3.25% Nickel; 1.20% Chromium; 0.12% Molybdenum	93xx
NICKEL–MOLYBDENUM STEELS	
1.75% Nickel; 0.25% Molybdenum	46xx
3.5% Nickel; 0.25% Molybdenum	48xx
CHROMIUM STEELS	
Low Chromium	50xx
Medium Chromium	51xxx
High Chromium	52xxx
CHROMIUM–VANADIUM STEELS	
0.80–1.00% Chromium; 0.10–0.15% Vanadium	61xx

f. Plasticity. With the increase of the load, the elastic behavior changes at some point of loading to plastic. The stretched metal never returns to its original dimension even if the load is removed. In other words, the metal is permanently deformed or plastically deformed. Therefore, plasticity can be defined as the ability of a material to assume deformation without breaking.

g. Ductility. Ductility is the ability of a metal to become permanently stretched without breaking or deforming. Each metal has a ductility limit beyond which fracture will occur. Prior to reaching this limit, the metal simply remains elongated.

h. Toughness. Toughness is the ability of a metal to resist rapid or sudden applications of force such as impact.

i. Hardness. Hardness is the ability of a metal to resist penetration by another metal or diamond indenter. The hardness of a metal is directly related to its machinability which will be discussed later. The relationship between the hardness and tensile strength in certain hardness ranges, will be discussed later.

j. Heat and Electrical Conductivity. Conductivity is the ability of a material to conduct or transfer heat or electricity.

4.3 CLASSIFICATION OF FERROUS (IRON) ALLOYS.

A numerical index system (see table 4–1) is used to identify the composition of the steels which enables the use of numerals that partially describe composition of material. The first digit indicates the type to which the steel belongs.

Table 4–2. Suggested Preheat and Interpass Temperatures for Various Alloy Bar Steels

Steel	Preheat and Interpass Temperature, −F For Section Thickness of To 1/2 inch	1/2 to 1 inch	1 to 2 inch
1330	350–450	400–500	450–550
1340	400–500	500–600	600–700
4023	100 min	200–300	250–350
4028	200–300	250–350	400–500
4047	400–500	450–550	500–600
4118	200–300	350–450	400–500
4130	300–400	400–500	450–550
4140	400–500	600–700	600–700
4150	600–700	600–700	600–700
4320	200–300	350–450	400–500
4340	600–700	600–700	600–700
4620	100 min	200–300	250–350
4640	350–450	400–500	450–550
5120	100 min	200–300	250–350
5145	400–500	450–550	500–600
8620	100 min	200–300	250–350
8630	200–300	250–350	400–500
8640	350–450	400–500	450–550

For example: ”1” indicates a carbon steel; ”2” indicates a nickel steel; and ”3” indicates a nickel chromium steel. In the case of simple alloy steels, the second digit indicates the approximate percentage of predominant alloying element. The last two or three digits indicate approximate carbon content in hundredths of one percent. Table 4–2. Suggested Preheat and Interpass Temperatures for Various Alloy Bar Steels

a. Carbon Steels.

(1) Steel containing carbon in the range of 0.l0–0.30% is classified as low carbon steel. Low carbon steels are in the range of 1010 through 1030 of numerical system described in Table 4–1. The steels of this grade are easy to weld without any preparations such as post and preheat treatments.

(2) Steel containing carbon in the range from 0.30–0.50% is classified as medium carbon steel. They are weldable with certain precautions requiring preheat and post heat treatments.

(3) Steel containing carbon in the range of 0.50–1.05% is classified as high carbon steel. In fully heat treated conditions high carbon steel is very hard and welding should be avoided.

b. Alloy Steels. In hardening steel, the carbon plays the most important role. The hardness attainable in the steel is dependent upon the amount of carbon only. It is difficult, however, to heat treat high carbon steel unless other alloying elements, such as nickel, chromium, molybdenum and vanadium are used. Some benefits of adding alloying elements are as follows:

(1) A lower percentage of carbon is required for hardening. Lowering the carbon content makes the steel more ductile and less susceptible to embrittlement cracks.

(2) A lower critical temperature range is required which permits the use of lower heating temperatures for hardening.

(3) Corrosion resistance is increased. For example: the 18% chromium and 8% nickel stainless steel.

Table 4-3. Various Classes of Aluminum and Aluminum Alloys

NUMERALS (and digits)	CLASS OF ALUMINUM/ALUMINUM ALLOY
1xxx	Aluminum 99.0% of minimum and greater
2xxx	Copper is major alloying element
3xxx	Manganese is major alloying element
4xxx	Silicon is major alloying element
5xxx	Magnesium is major alloying element
6xxx	Magnesium and silicon are major alloying elements
7xxx	Zinc is major alloying element

(4) The lower heat treating temperature requirements reduce the dangers of overheating, excessive grain growth and the consequent development of brittleness.

(5) The characteristic of depth hardening from the addition of nickel to steel as an alloy results in good mechanical properties after quenching and tempering. At a given strength, the nickel steels provide greatly improved elastic properties, impact resistance and toughness.

c. Preheating of Steel.

(1) Suggested preheating and interpass temperatures for 18 alloy bar steels are given in table 4-2. These suggested temperatures are based on the use of low-hydrogen electrodes. The preheating temperature increases with the carbon content or hardenability of the steel and with the section thickness. If local preheating is used, the full thickness of the joint and about 3 in. (or a distance equal to base-metal thickness, whichever is smaller) on either side of the joint, should be preheated. The preheating temperatures suggested in table 4-2 are intended as a guide.

(2) Under certain circumstances, such as very low restraint, alloy steels can be welded successfully without preheating. Often, preheating of the entire weldment is impractical, so that if preheating is needed, it must be done locally.

4.4 CLASSIFICATION OF ALUMINUM ALLOYS.

The basic numerical classification system:

a. Aluminum and aluminum alloys have a standard four digit numbering system (see Table 4-3). The first digit represents the major alloying element, the second digit identifies modification and the last two digits serve only to identify different aluminum alloys which are in common commercial use except in the Ixxx class. In the Ixxx class the last two digits indicate the aluminum content over 99 percent in hundredths of one percent. Therefore, 1017 indicates a minimum aluminum composition of 99**%;** the 0 indicates it is the original composition; and the 17 indicates aluminum content 99.17%. In number 3217, the 3 indicates a manganese alloy; the 2 indicates the second modification of this alloy, and the 17 indicates a commonly used commercial alloy.

b. Temper Designation of Aluminum and Aluminum Alloy. In high purity form, aluminum is soft and ductile. Most commercial uses, however, require greater strength than pure aluminum affords. This is achieved in aluminum first by the addition of other elements to produce various alloys which, singly or in combination, impart strength to the metal. Further strengthening is possible by means which classify the alloys roughly into two categories: non-heat treatable and heat-treatable.

(1) Non-heat-treatable alloys. The initial strength of alloys in this group depends upon the hardening effect of elements such as manganese, silicon, iron and magnesium, singly or in various combinations. The non-heat-treatable alloys, therefore, are usually designated in the 1000, 3000, 4000, or 5000 series. Since these alloys are workhardenable, further strengthening is made possible by various degrees of cold working, denoted by the "H" series of tempers as shown below:

H1: strain hardened
H2: strain hardened and partially annealed
H3: strain hardened and stabilized
F : as fabricated
O : annealed

The second number added to the above top three designations (HI, H2 and H3) indicates the degree of hardness.

2 = 1/4 hard	H12, H22, H32
4 = 1/2 hard	Hl4, H24, H34
6 = 3/4 hard	Hl6, H26, H36
8 = Full hard	H18, H28, H38

Example: 5052–H24 – strain hardened and partially annealed to half hard.

(2) Heat–treatable alloys. The initial strength of alloys in this group is enhanced by the addition of alloying elements such as copper, magnesium, zinc and silicon. Since these elements show increasing solubility in aluminum with increasing temperature, it is possible to subject them to thermal treatments which will impart pronounced strengthening.

(a) The first step, called solution heat treatment, is an elevated temperature process designed to put the soluble elements into the solid solution. This is followed by rapid quenching, usually, which momentarily ”freezes” the structure in a short time to make the alloy very workable. It is at this stage that some fabricators retain this more workable structure by storing the alloys at below freezing temperature until they are ready to form the part. Example: Some rivets are stored in the freezer and taken out just prior to installation.

(b) At room or elevated temperatures, however, the alloys are not stable after quenching, and precipitation of the constituents from the supersaturated solution begins. After a period of several days at room temperature, termed aging or room–temperature precipitation, the alloy is considerably stronger. Many alloys approach a stable condition at room temperature, but some alloys, particularly those containing magnesium and silicon or magnesium and zinc, continue to age harden at room temperature for long periods of time.

(c) By heating for a controlled time at slightly elevated temperatures, even further strengthening is possible and properties are stabilized. This process is called artificial aging or precipitation hardening. By the proper combination of solution heat treatment, quenching, cold working and artificial aging, the highest strengths are obtained.

(d) Numerals 1 through 10 following the ”T” and ”F”, ”0”, ”W” indicate the basic treatment of the heat treatable alloys as follows:

- –F: As fabricated
- –0: Annealed Solution heat treated (unstable condition)
- –T1: Cooled from an elevated temperature shaping process and naturally aged to a substantially stable condition
- –T2: Annealed (cast product only)
- –T3: Solution heat treated and then cold worked
- –T4: Solution heat treated and naturally aged
- –T5: Cooled from elevated temperature shaping process and then artificially aged
- –T6: Solution heat treated and then artificially aged
- –T7: Solution heat treated and then overaged/ stabilized
- –T8: Solution heat treated, cold worked, and then artificially aged
- –T9: Solution heat treated, artificially aged, then cold worked
- –T10: Cooled from an elevated temperature shaping process, cold worked and then artificially aged

Additional digits may be added to designate –T1 through –T10 to indicate a variation in treatment such as straightening after heat treatment. –F, –O and –W are not followed by second digits.

Example: 7075–T6 – copper–zinc aluminum alloy, solution heat treated and then artificially aged condition.

c. Clad Alloys. The heat treatable alloys in which copper or zinc are major alloying constituents, are less resistant to corrosive attack than the majority of non–heat–treatable alloys. To increase the corrosion resistance of these alloys in sheet and plate form, they are often clad with high–purity aluminum, a low magnesium–silicon alloy, or an alloy containing **l** percent zinc. The cladding is usually from 2–1/2 to 5 percent of the total thickness on each side or one side.

d. Preheating of Aluminum.

(1) In gas shielded arc welding of aluminum alloys, preheating parts to be welded is normally done only when the temperature of the parts is below 32−F or when the mass of the parts is such that the heat is conducted away from the joint

faster than the welding process can supply it. Preheating may be advantageous for GTAW with alternating current of parts thicker than about 3/16 inch and GMAW of parts thicker than about 1 inch. Gas tungsten arc welding with DCEP is limited to thin material, and preheating is not necessary with this process. Thick parts also should not be preheated when GTAW using DCEN, because of the high heat input provided to the work. Preheating can also reduce production costs because the joint area reaches welding temperature faster, thus permitting higher welding speeds.

(2) Various methods can be used to preheat the entire part or assembly to be welded, or only the area adjacent to the weld can be heated by use of a gas torch. In mechanized welding, local preheating and drying can be done by gas or tungsten arc torches installed ahead of the welding electrode.

(3) The preheating temperature depends on the job. Often 200−F is sufficient to ensure adequate penetration on weld starts, without readjustment of the current as welding progresses. Preheating temperature for wrought aluminum alloys seldom exceeds 300−F, because the desirable properties of certain aluminum alloys and tempers may be adversely affected at higher temperatures. Aluminum–magnesium alloys containing 4.0 to 5.5% Mg (5083, 5086 and 5456) should not be preheated to more than 200−F, because their resistance to stress corrosion cracking is reduced.

(4) Large or intricate castings may be preheated to minimize thermal stresses and to facilitate attainment of the welding temperature. After welding, such castings should be cooled slowly to minimize the danger of cracking. Castings that are to be used in the heat treated condition should be welded before heat treatment or should be reheat treated after welding. Preheating and the heat of welding may affect the corrosion resistance of some alloys, such as alloy 520, unless welding is followed by heat treatment.

4.5 CLASSIFICATION OF MAGNESIUM ALLOYS.

Basic Classification. The current system used to identify magnesium alloys is a two letter, two or three digit number designation in that order. The letters designate the major alloying elements, (arranged in decreasing percentage, or in alphabetical order if the elements are of equal amounts), followed by the respective digital percentages of these elements. The percentage is rounded off to the nearest whole number or if a tolerance range of the alloy is specified, the mean of the range (rounded off to nearest whole number) is used. A suffix letter following the percentage digits, denotes the latest qualified revision of the alloy. For example: Alloy Designation AZ 92A would consist of 9% (mean value) aluminum and 2% (mean value) zinc as the major alloying elements. The suffix ”A” indicates this is the first qualified alloy of this type. Some of the letters used to designate various alloying elements are:

A	Aluminum
E	Rare earth
H	Thorium
K	Zirconium
M	Manganese
Z	Zinc

4.5.1 Temper Designation of Magnesium Alloys. The temper (hardness) designation is similar to the one used for heat treatable aluminum alloys. The hyphenated suffix symbol which follows an alloy designation denotes the condition of temper. The meaning of the symbols are as follows:

–AC	As–casted
–F	As–fabricated
–0	Annealed
–W	Solution heat treated (unstable temper)
–T2	Annealed (cast product only)
–T3	Solution heat treated and then cold worked
–T4	Solution heat treated
–T5	Artificially aged only
–T6	Solution heat treated and then artificially aged

4.6 HEAT TREATMENT OF STEEL.

4.6.1 Heat Affected Zone (HAZ). The properties of the metal adjacent to the weld joint are changed during welding. The metal at HAZ does not actually melt but it can reach temperatures close to the melting point therefore altering structural and physical properties which is generally harmful and should be taken into consideration when dealing with the ultimate tensile strength of a welded joint.

4.6.2 Stress Relief Heat Treatment. Welding a part usually results in localized residual stresses that sometimes approach levels of the yield strength of the metal. This will eventually distort or crack the part. Stress relief heat treatment is utilized to relieve this stress that is locked in the part after welding. Typical stress relief temperatures for low alloy steel are attained by uniformly heating the part in a temperature range of 1100−–1200−F, holding at this temperature for a predetermined time followed by uniform cooling to room temperature.

4.6.3 Annealing. Annealing is performed to soften the part to improve machinability as well as dimensional stability. It consists of heating to and holding at a certain temperature followed by cooling to room temperature at a different rate. The higher the carbon content, the lower the annealing temperature. For example: the annealing temperature of low carbon steel is 1575−–l650−F compared to 1450−–1600−F for medium carbon steel.

4.6.4 Hardening. As discussed earlier in the alloy steel section, the carbon content of a steel determines the maximum attainable hardness. Therefore, the hardening of steel is the art of controlling the distribution of carbides in the steel. It is accomplished by heating the part to an elevated temperature, then cooling it rapidly (called quenching) in oil or water. The carbides are precipitated as very fine particles which is associated with high hardness of the steel.

4.6.5 Normalizing. A process in which an iron–base alloy is heated to a temperature above the transformation range and subsequently cooled in still air at room temperature.

4.6.6 Tempering. The steel that has been hardened by rapid cooling or quenching is often harder than necessary and too brittle for most purposes. It also contains residual stresses arising from the quenching. In order to relieve the stress and reduce the brittleness or restore toughness, the hardened steel is almost always tempered. Tempering consists of heating the steel to a 370− – 1100−F range depending on the desired hardness. The higher the tempering temperature, the softer the steel becomes. In other words, as the tempering temperature increases, the toughness increases and hardness decreases.

4.6.7 Surface Hardening. Gears must have very hard teeth to prevent wear, but at the same time they require softer and tougher cores to absorb impact loads during operation. Case hardening or surface hardening produces a hard wear resistance surface but leaves a tough core for this type of application. Since low carbon steel cannot be hardened to any great extent by the hardening process, hardening of the surface or case is accomplished by increasing the carbon content on the surface by the case hardening process. The depth of the portion into which the carbon has been diffused is called case depth. Welding is not recommended on case hardened parts.

4.7 HARDNESS TESTING.

Hardness testing is an important tool in determining the results of the heat treatment as well as the condition of the metal before heat treatment and must, therefore, be carefully considered in connection with this work. The most common hardness testers in general use are: Brinell, Rockwell and Vickers. In certain hardness ranges, values from these testers can be interchangeable.

4.7.1 Relationship Between Hardness and Tensile Strength. The approximate relationship between the tensile strength and hardness is indicated in table 4–4. This table is to be used as a guide. It is usually applied to the plain carbon and low alloy steels and to the metals with tensile strengths greater than 100,000 psi. The tensile strength–hardness relation ship is quite uniform for parts which are sufficiently large and rigid to permit obtaining a full depression of a flat surface without deflection of the piece. For cylindrical parts of less than one inch in diameter, and all tubing, the Rockwell reading will be lower because the part has a tendency to yield on pressure and become egg–shaped. Therefore, a correction factor has to be added to obtain a correct hardness. Any process which affects the surface such as buffing and plating, or the presence of decarburized, or porous areas and hard spots, will affect the corresponding relationship between hardness and tensile strength. Therefore, these surfaces must be adequately removed by sanding or grinding before the measurements are made.

Example: The part measured Rockwell C hardness 40.
What is the approximate tensile strength of this part?

From table 4–4, cross over from 40 in the C scale and the approximate tensile strength is 181 KSI or 181,000 psi.

4.8 FILLER MATERIALS.

NOTE

For a general reference on selection of filler metal to alloy, see tables 4–5 to 4–12.

The medium carbon (AISI/SAE) grades of the low alloy steels are more difficult to weld than the low carbon grades. If welding of this series is to be successful, close control of procedures is required. Preheating is necessary except for 8630 and 4130, (and even for these grades if shape of part/assembly is complicated). The medium carbon grades in the as–welded condition are inherently brittle and require normalizing/stress relieving or heat treatment for successful welding. In some instances for the welding of heavy sections, intermediate stress relief is used by heating to the stress relief temperature from the preheat temperature, holding for 5–6 hours, and then lowering to the preheat temperature to complete the weld. After welding is completed, the part is given a final stress relief or heat treat. For best results, stress relief or heat treatment should be accomplished immediately after welding before material is allowed to cool below minimum interpass/preheat temperature (for some alloys this is a mandatory requirement), and in any case before the material is allowed to cool to room temperature. Although thin material in grades 4130 and 8630 can be welded without preheat, a preheat temperature of 200_ to 300_ F is recommended for best results.

CAUTION

Do not degrease titanium or titanium parts, bearings, rubber or plastic parts which can be attacked by organic solvents.

4.9 DEGREASING.

Degreasing is a cleaning method designed to remove oil, grease and preservative compounds from metal. The part is immersed in the solution so that the grease, oil and preservative compounds are carried away.

Table 4–4. Approximate Hardness – Tensile Strength Relationship of Carbon And Low Alloy Steels

Rockwell		Vickers Diamond Pyramid 50 Kg Load	Brinell 3000 Kg Load – 10 mm Ball		Tensile Strength 1000 lb. per sq. in.
C	B				
C150 Kg Load	100 Kg Load 1/16 Ball		Tungsten Carbide Ball	Steel Ball	
67		918	820	717	
66		884	796	701	
65		852	774	686	
64		822	753	671	
63		793	732	656	
62		765	711	642	
61		740	693	628	
60		717	675	613	
59		694	657	600	
58		672	639	584	
57		650	621	574	
56	121.3	630	604	561	
55	120.8	611	588	548	
54	120.2	592	571	536	
53	119.6	573	554	524	283

Table 4–4. Approximate Hardness – Tensile Strength Relationship of Carbon And Low Alloy Steels (Cont.)

Rockwell		Vickers Diamond Pyramid 50 Kg Load	Brinell 3000 Kg Load – 10 mm Ball		Tensile Strength 1000 lb. per sq. in.
C	B				
C150 Kg Load	100 Kg Load 1/16 Ball		Tungsten Carbide Ball	Steel Ball	
52	119.1	556	538	512	273
51	118.5	539	523	500	264
50	117.9	523	508	488	256
49	117.4	508	494	476	246
48	116.8	493	479	464	237
47	116.2	479	465	453	231
46	115.6	465	452	442	221
45	115.0	452	440	430	215
44	114.4	440	427	419	208
43	113.8	428	415	408	201
42	113.3	417	405	398	194
41	112.7	406	394	387	188
40	112.1	396	385	377	181
39	111.5	386	375	367	176
38	110.9	376	365	357	170
37	110.4	367	356	347	165
36	109.7	357	346	337	160
35	109.1	348	337	327	155
34	108.5	339	329	318	150
33	107.8	330	319	309	147
32	107.1	321	310	301	142
31	106.4	312	302	294	139
30	105.7	304	293	286	136
29	105.0	296	286	279	132
28	104.3	288	278	272	129
27	130.7	281	271	265	126
26	102.9	274	264	259	123
25	102.2	267	258	253	120
24	101.5	261	252	247	118
23	100.8	255	246	241	115
22	100.2	250	241	235	112
21	99.5	245	236	230	110
20	98.9	240	231	225	107
19	98.1	235	226	220	104
18	97.5	231	222	215	103
17	96.9	227	218	210	102
16	96.2	223	214	206	100
15	95.5	219	210	201	99
14	94.9	215	206	197	97
13	94.1	211	202	193	95

Table 4–4. Approximate Hardness – Tensile Strength Relationship of Carbon And Low Alloy Steels (Cont.)

Rockwell		Vickers Diamond Pyramid 50 Kg Load	Brinell 3000 Kg Load – 10 mm Ball		Tensile Strength 1000 lb. per sq. in.
C	B				
C150 Kg Load	100 Kg Load 1/16 Ball		Tungsten Carbide Ball	Steel Ball	
12	93.4	207	199	190	93
11	92.6	203	195	186	91
10	91.8	199	191	183	90
9	91.2	196	187	180	89
8	90.3	192	184	177	88
7	89.7	189	180	174	87
6	89	186	177	171	85
5	88.3	183	174	168	84
4	87.5	179	171	165	83
3	87	177	169	162	82
2	86	173	165	160	81
1	85.5	171	163	158	80
0	84.5	167	159	154	78
	83.2	162	153	150	76
	82	157	148	145	74
	80.5	153	144	140	72
	79	149	140	136	70
	77.5	143	134	131	68
	76	139	130	127	66
	74	135	126	122	64
	72	129	120	117	62
	70	125	116	113	60
	68	120	111	108	58
	66	116	107	104	56
	64	112	104	100	54
	61	108	100	96	52
	58	104	95	92	50
	55	99	91	87	48
	51	95	86	83	46
	47	91	83	79	44
	44	88	80	76	42
	39	84	76	72	40
	35	80	72	68	38
	30	76	67	64	36
	24	72	64	60	34
	20	69	61	57	32
	11	65	57	53	30
	0	62	54	50	28

4.9.1 Steam Cleaning.

4.9.1.1 General. Steam cleaning is a superficial cleaning process that is used primarily when it is not desirable to remove paint and surface coatings from ferrous and nonferrous jet engine parts. To clean properly with steam it is necessary to add a cleaning compound. Do not steam clean oil impregnated parts.

NOTE

Contact the local safety and health entity for permission and safety procedures.

4.9.1.2 Preparation of Compounds.

WARNING

Wear rubber gloves, an apron and face shield while steam cleaning. When using a liquid or powder, follow manufacturer's instructions.

4.9.1.3 Procedure.

a. Set the steam valve to the strength and force required for the cleaning job at hand. Hold the steam gun about 12 inches from the part and at about a 45–degree angle to the surface being cleaned. After steam cleaning, parts should be given a final rinse with clear water to remove any residue of cleaning compound, and be thoroughly dried. When rust protection is needed, it should be applied immediately after drying.

NOTE

For best results, the steam valve should be opened only enough to produce a wet spray with high impact upon the surface being cleaned.

4.9.2 Dry Abrasive (Grit) Blasting.

a. General.

(1) Dry abrasive blast can be used for the removal of heat scale, carbon deposits, corrosion and rust on critical parts where slow cutting action is desired, and for paint and thermal sprayed coating surface preparations, where limited cutting action is desired.

4.9.2.1 Material and Equipment.

NOTE

The type and size of the abrasive may vary for different parts. Refer to the applicable manual to determine the type and size of the abrasive material required for that part.

A standard type of Dry Blast Cabinet and shop compressed air supply is all the equipment required.

4.9.2.2 Procedure.

WARNING

Grit blast equipment used for titanium or magnesium should be cleaned regularly to prevent accumulation of metal dust which could create a fire hazard.

CAUTION

Dry abrasive blasting shall never be used to clean titanium or magnesium parts or alloys of either material, unless specifically directed by the maintenance manual. Avoid excessive blasting. Perform the cleaning operation so that the blast will not dwell in one spot. The blast shall be directed at an angle so as to sweep across the surface, not perpendicular to it.

a. Mask all plated or machined surfaces and other areas to protect them from abrasive blast and cover all parts, pockets, cavities, hoses, and tubes to prevent entry of abrasive which may be difficult to detect and remove after cleaning.

b. Grit–blast parts only to the extent necessary to obtain a uniformly clean surface on all exposed areas. Unless otherwise specified in the applicable engine manual, use 120 or 220 mesh aluminum oxide grit. The recommended air pressure is 25–90 psi with the nozzle held at a distance of 5–8 inches from the part.

c. Blow all residual grit from the part, using clean, dry, compressed air.

d. After blasting, visually inspect the part thoroughly to insure that no abrasive material is trapped in cavities.

4.9.3 Dry Abrasive (Shell) Blasting.

a. General.

(1) Dry abrasive blasting, using crushed shells as the abrasive medium, is an effective method of cleaning light scale or carbon deposits, corrosion and rust from parts where slow cutting action is desired.

NOTE

The type and size of abrasive may be different for some parts. Type and size will be specified in the maintenance or overhaul manual.

4.9.3.1 Materials and Equipment.

a. Use a mixture of 50% crushed walnut shells and 50% rice hulls, unless otherwise specified in the ap–plicable maintenance or overhaul manual.

b. A standard type of dry blast cabinet with a gun nozzle size of 1/4 inch should be used.

4.9.3.2 Procedure.

a. Mask all parts that are to be grit–blasted to protect plated or coated finishes or machined surfaces and to keep abrasives from entering cavities, pockets, tubes, hoses or manifolds from which grit may be difficult to detect and remove after blasting.

b. Clean all exposed surfaces of the parts, using a mixture of 50 percent crushed walnut shells and 50 percent rice hulls. Mixtures are by volume in accordance with the following recommendations:

(1) Recommended distance of gun from part is 10–12 inches. Keep the gun at least 8 inches away from part.

(2) Air pressure: 80–100 psi.

c. Perform the cleaning operation so that the grit blast does not dwell in one spot. The most effective method is to direct the blast stream at an angle across the surface being cleaned.

d. Inspect to make sure that no abrasive is trapped in the part.

4.9.4 Wet Abrasive (Grit) Blasting, Type 1.

4.9.4.1 General.

a. Wet abrasive blast is an effective method of removing heat scale, carbon deposits, rust, and temporary markings from metal parts, and for producing a uniform satin finish on parts having simple or complex shapes. This type of blasting does not remove metal rapidly; hence surfaces can be refinished without changing dimensions significantly. Mating surfaces after wet abrasive blasting are less likely to shift during assembly.

NOTE

The type and size of abrasive may be different for some parts. Type and size will be specified in the applicable engine manual.

4.9.4.2 Procedure.

a. Mask all identification markings and other areas as required. No other masking is necessary.

CAUTION

Do not permit the blast stream to dwell in one spot; this will cause excessive removal of metal. Direct the blast to sweep across the surface at an angle, not perpendicular to it. If turbine disks and spacers are blasted, direct the blast radially outward across the surface to avoid blasting the dovetails.

Using grits of 500 mesh or larger may cause plugging of small holes and internal passages found in such parts as turbine buckets and vanes. Once parts are plugged, it is practically impossible to clean them out.

b. Wet blast the exposed surface of parts using the slurry mixture. Use an air pressure of approximately 60–90 psi for applying the wet abrasive.

c. Immediately following the abrasive blasting, pressure–rinse the parts with hot water, making sure that no abrasive is trapped in any cavities. Dry, using clean, dry, shop air.

d. Visually inspect to determine adequacy of cleaning and uniformity of surface finish.

e. Apply rust preventive as necessary.

4.9.5 Cleaning of Aluminum. Proper cleaning is often an important factor that controls the final results of a welding operation. This is especially true when welding with oxyacetylene, oxyhydrogen or other types of gas and spot welding (resistance welding).

CAUTION

Check with the local health and safety entity for permission and procedures to use these toxic/hazardous materials.

4.9.5.1 The degreasing operation will remove the oil/grease and dirt but it has no effect on the oxide film. To remove the oxide film, parts should be cleaned on both sides of the area to be welded with a scouring pad, Type II, Class 1, Fed Spec LP OOSOC. Parts shall be immersed for twenty (20) minutes in a corrosion removing compound type 2, NSN 6850–00–655–1292 until surface shows no water break and then rinsed with tap water.

4.9.5.2 Welding shall be accomplished immediately after deoxidizing and no later than 12 hours after the deoxidizing operation.

4.9.5.3 The chemical cleaning operation shall be precisely timed since over or under application time will increase the contact resistance and any chemical that will remove the oxide will also attack the aluminum.

4.9.5.4 Mechanical Oxide Removal. Stainless steel brushes (hand or rotary), stainless steel wool and some abrasives can be used to remove oxides from unclad aluminum. The strand diameter of the wire brush utilized shall not be over 0.005 inch. Abrasive mats Specification MIL–A–9962, Type 1, Grade AAAI1(very fine) can also be used.

4.9.5.5 Mechanical removal of oxides shall be confined to the immediate weld area; application to other surfaces of the metal shall be avoided.

4.9.5.6 Do not over apply the mechanical cleaning. Application should be controlled and applied only until the surface is clean of oxide.

4.10 PREPARATION FOR WELDING.

4.10.1 Inspection Before Welding. It is important that the ends of a crack be found so that the crack will be completely welded. If the crack is not completely welded, it may grow after welding. Proceed as follows:

a. Fluorescent penetrant inspect defective area.

b. Mark the ends of the crack, using chalk, so that the marking will not be removed by degreasing.

c. Degrease the part. Refer to the cleaning section.

4.10.2 Preparing Defects For Welding. When preparing a part for welding, it is extremely important that all contaminants be removed from the repair area. Contaminants not removed can cause a crack to form in the weld after the part is returned to service. Prepare the part as follows:

a. Degrease the part and dry the part, using filtered compressed air.

b. The defects must be prepared by grinding or rotary filing, etching the exposed surface, and reinspecting the area using NDI methods before welding. Remove all paint, scale and carbon deposits from both front and back surfaces of the weld area, using a stainless steel rotary brush or 80–320 grit abrasive roll, disk, or sheet. Remove all anodic or other chemical protective coating from front or back surfaces of aluminum parts within 1/2 inch of the weld area, using 160–180 grit abrasive roll, disk or sheet.

CAUTION

Use approved pure dye markers for marking engine hardware. Using nonapproved markers can leave harmful elements on the parts. These elements can cause intergranular attack. If a part has been inadvertently marked with an unauthorized material, remove all traces of the material.

c. Mark ends of the crack.

d. Using a stainless steel rotary brush, abrasive roll, or either dryblast or wet–blast process, clean the area to be repaired; clean both sides of part if possible. DO NOT use glass beads with the wet–blast process. If grit–blast is used, the surface shall be polished with the rotary stainless to remove all grit–blast residue on the surface.

e. Using a bright light and a 10–power magnifying glass, find the exact end of the crack.

f. If necessary, remark the ends of the crack.

g. If a crack extends into a rivet hole, remove the rivet before welding. (The repair–weld must be ground flush and the hole redrilled or reamed before replacing the rivet.)

h. Using an electric or air hand– grinder and suitable carbide rotary grinding bits and stones (figure 4–1), completely grind out the crack as shown in figure 4–2.

(1) Select a grinding bit or stone based on the width of the crack to be ground out. Keep the groove as narrow as possible.

(2) If the crack does not go through the material, grind it out completely. Remove stock from both edges of the crack to the minimum depth and width that exposes sound metal, and to a length approximately 1/8 inch beyond each end of crack.

(3) If the crack goes through the material whose thickness is less than 0.045 inch grind it out, removing about half of the material thickness.

(4) If the crack goes through the material that is 0.045–0.090 inch thick, grind it out on one side, removing about 75% of the material thickness. Weld this side; then grind out the remainder of the crack on other side of part.

(5) If the crack is more than 0.090 inch thick, grind it out to within 0.030 inch of opposite surface.

(6) If there is more than one layer of material, grind out the crack completely, even if this requires grinding into the next layer.

(7) Grind 1/8 inch beyond the end of all cracks, if possible.

i. If the part has not been blasted, remove the surface oxides, using fine abrasive cloth or soft abrasive wheel.

(1) Do not reduce the material thickness.

(2) Clean the surface within 1/4 to 1/2 inch of the crack to remove oxides.

(3) Clean the back side of the crack also if accessible.

j. Grind out all burned metal.

k. Grind out old filler material.

WARNING

Do not inhale vapors from solvents. Do not use solvents near open flame or sparks.

l. If the prepared area is oily or greasy, clean with solvent.

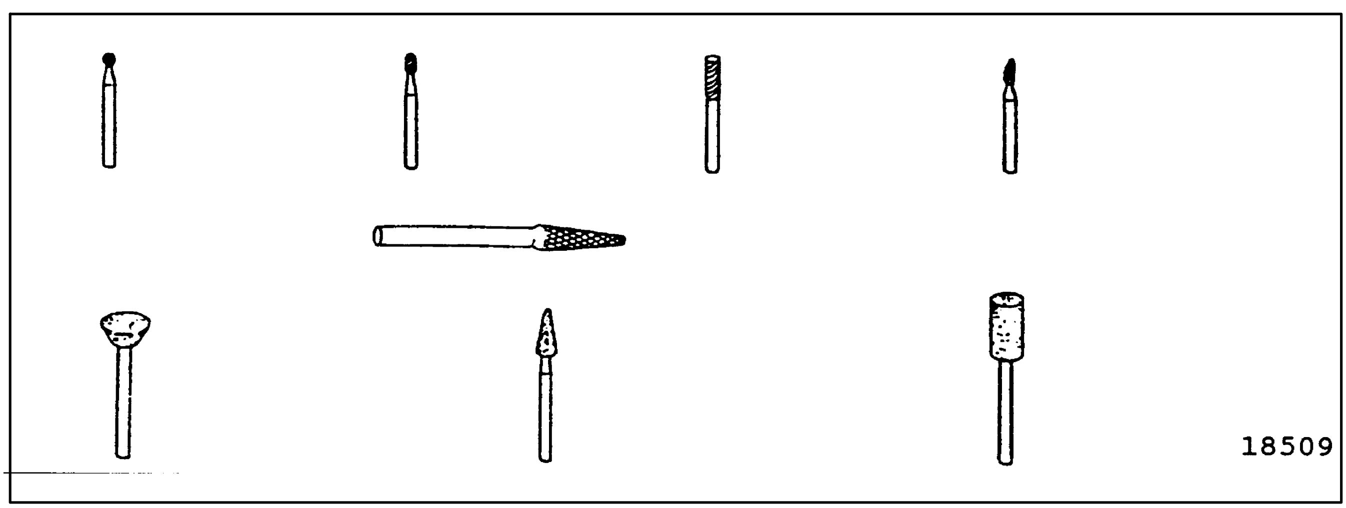


Figure 4–1. Rotary Grinding Bits and Stones

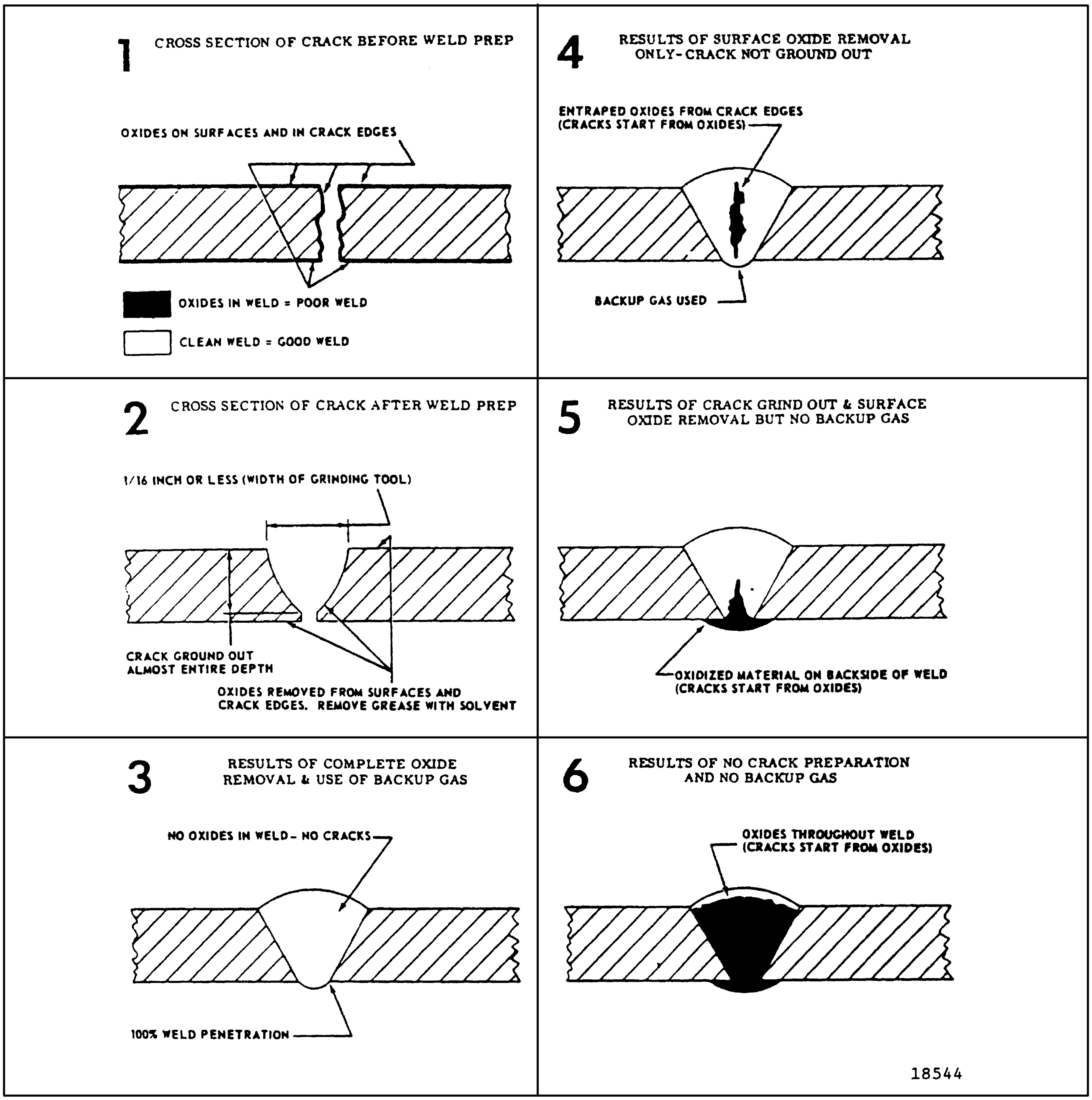


Figure 4-2. Crack Repair-Weld Practices

m. Where welding is done from both sides, the root shall be ground or rotary filed to sound metal.

n. Polish all filler wire with an abrasive mat and wipe clean.

o. Filler materials for various metals are described in tables 4-5 through 4-12. These tables are to be used only as a guide and are not intended to replace requirements specified by blueprints, technical orders or other engineering data.

p. Amperages may vary with thickness and type of material to be repair-welded. Table 4-13 lists variances due to thickness and type of current used.

Table 4–5. Welding Characteristics – General, Steels Other Than Stainless

STEEL DESIGNATION	COVERED ELECTRODE	FILLER ROD	HEAT TREATMENT		REMARKS
			PREHEAT	POSTHEAT	
(Low Carbon) 1010 thru 1030	MIL–E–6843 Class A or B E6010	MIL–R–5632 Class l	None required if above 60−F.	If post heat used do not heat above 300−F and air cool.	These are low carbon steels, not requiring heat treatment.
(Low Carbon) Corten	QQ–E–450 E7016 or E7018	MIL–R–5632 Class 1	Same	Same	This is a low carbon alloy steel Not heat treatable.
(Low Carbon) NAX AC 9115	E6015, thin gauge, for arc welding; or MIL–E–22200 Types MIL–7015 for multipass welding.	MIL–R–5632 Class 2	Same	See Remarks	Light gauge should be normalized.
(Medium Carbon) 1035 1040, 1045	MIL–8018 E6015 E6016	MIL–R–5632 Class 2	300− –500−F	1035 should be stress relieved 1100− –1200−F. Normalize 1040 1045	See text.
(Medium Carbon) 1050	MIL–8018 E6015 E6016	MIL–R–5632 Class 2	300− –800−F	Normalize	This steel is difficult to weld.
(High Carbon) 1055, 1060 1070, 1095		MIL–R–5632 Class 2	500− –800−F	Normalize	This steel is difficult to weld.
(Free Cutting) 1112			200−F	Normalize	This is a difficult alloy to weld. Best results obtained by use of electrode E8015 AWS, direct current reverse polarity brazing characteristics are good.

Table 4–5. Welding Characteristics – General, Steels Other Than Stainless (Cont.)

STEEL DESIGNATION	COVERED ELECTRODE	FILLER ROD	HEAT TREATMENT PREHEAT	POSTHEAT	REMARKS
(Free Cutting) 1117, 1137	E8015 AWS	MIL–R–5632 Class 2	200−F	Normalize	
Listed for reference only, alloy not currently being produced.					
(Nickel Alloy) 2317	MIL–E–6843 E10010 C1 D or E10013 C1 C	MIL–R–5632 Class 2	200−F –400−F	Normalize	This steel has good weldability characteristics.
Listed for reference only, alloy not currently being produced.					
(Nickel Alloy) 2330– 2340	MIL–E–22200 AWS E8018–C2	MIL–R–5632 Class 2	200−F –500−F	Normalize	Not recommended for welding.(This steel has high car-bon content.)
Listed for reference only, alloy not currently being produced.					
(Nickel Alloy) 2515	MIL–E–22200 Type MIL– 12016 Class 1	MIL–R–5632 Class 2	200−F –400−F	Normalize	
(Ni Cr) 3115	MIL–E–22200 Type MIL– 11015	MIL–R–5632 Class 2	200−F –500−F	Normalize	
(Ni Cr) 3140	MIL–E–22200/ 1C Type MIL– 9018	MIL–R–5632 Class 2	200−F –500−F	Normalize	
(Ni Cr)	MIL–E–22200/ 1C	MIL–R–5632	200−F –300−F	Normalize	Preheating required before welding
(Cr–MO) 4130	AMS 6300 HT–4130 E8011	MIL–R–5632 Class 2 (see re-marks)	200−F –500−F	Normalize	Where heat treat-ment is not required MIL–R–5632 Class 1 rod may be used. If heat treatment is re-quired MIL–R–5632 Class 2 rod which is heat treatable may be used.

Table 4–5. Welding Characteristics – General, Steels Other Than Stainless (Cont.)

STEEL DESIGNATION	COVERED ELECTRODE	FILLER ROD	HEAT TREATMENT		REMARKS
			PREHEAT	POSTHEAT	
(Cr–Mo) 4037	E9015	MIL–R–5632 Class 2	200– –500–F	Normalize	Slightly lower weldability characteristics than 4130
(Cr–Mo) 4135	E–9015	MIL–R–5632 Class 2	200– –500–F	Normalize	
(Low Alloy) 17–22A (V)	MIL–E–6843 Class C or D	MIL–R–5632 Class 2	600–F	Normalize	Good weldability by any of the common welding methods.
(Cr–V) 4137 Co	E10015	------ MXW–2 WCX–2		250–F for 120 minutes	Good weldability using Tungsten–arc–inert gas method. Stress relief recommended after welding.
(Cr–Mo) 4140, 4150	E10015	MIL–R–5632 Class 2	600––800–F	Normalize	See 4340
(High Carbon) High Chromium 52100	E10015	------	------	Normalize	
(Low Alloy) Ladish–D–5–A	E10015	MIL–R–5632 Class 2	600–F	Normalize	This alloy is weldable in heavy sections employing techniques for welding high hardenability medium low alloy.
(Low Alloy) Hi–Tuf	E10015	------	600–F	Normalize	Weld by conventional methods using low hydrogen electrodes of similar composition.

Table 4–5. Welding Characteristics – General, Steels Other Than Stainless (Cont.)

STEEL DESIGNATION	COVERED ELECTRODE	FILLER ROD	HEAT TREATMENT PREHEAT	POSTHEAT	REMARKS
4330 VMOD 4337, 4340	MIL–E–22200 Type 260 E10016 E12015	MIL–R–5632 Class 2	600−F	DO NOT Normalize	Fusion or resistance welding not permitted on parts heat treated to 260,000–280,000 PSI tensile due to embrittlement of the joint area. Spot/seam welding not recommended due to air hardening.
Nitralloy 136 Mod	See Remarks E8018–C2	See Remarks		Normalize before machining.	Welding is most successful by use of 2.5% chromium rod with the atomic hydrogen process. If nitriding is not required, conventional methods maybe used, using MIL–R–5632 Class 2 or MIL–E–6843 Class C or D.
(Ni–Mo) 4615	E90I8G	MIL–R–5632 Class 2	400−F	600−F	
(Ni–Mo) 4620	E9018G	MIL–R–5632 Class 2	600−F	800−F	
(Ni–Mo) 4640	E9018G	MIL–R–5632 Class 2	600−F	800−F	
6150 6152	EA018G	MIL–R–5632 Class 2			
8615 8617 8620	E90I8G	MIL–R–5632 Class 2	200− –300−F	Normalize	Low hydrogentype electrodes (particularly when low preheat and interpass temperatures are employed) are generally used for welding this group.

Table 4–5. Welding Characteristics – General, Steels Other Than Stainless (Cont.)

STEEL DESIGNATION	COVERED ELECTRODE	FILLER ROD	HEAT TREATMENT PREHEAT	POSTHEAT	REMARKS
8735	E10018G	MIL–R–5632 Class 2	200– –300–F	Normalize	
8630	E9018G	MIL–R–5632	300– –500–F	Stress Relieve 1100– – 1200–F or Normalize	Shielded–arc carbon molybdenum electrodes are recommended. Bare electrodes produce brittle welds.
D–5–A	––––––	––––––	450– –550–F	575–625, 1–1/2 hr cool in still air to 300–F followed by immediate stress relief. Alternate, transfer to furnace at pre–heat temp & normalize at 1725–1775, 30 minutes; air cool.	Weldable in heavy section using normal techniques required for welding high hardenable medium carbon low alloy steel. Sections less than 0.125 in some instances may be welded by tungsten inert gas process without preheating.

Table 4–6. Fusion Welding Characteristics of Corrosion Resisting Steel – General

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	COVERED ELECTRODE	FILLER-WIRE/ ROD	PREHEAT	POSTHEAT-TREAT	
301 302	Austenitic	308	MIL–E–22200	MIL–R–5031 Class I	None required if above 60–F material should be annealed.	Anneal after welding type 301 at 1950– –2050–F, 1 hour each inch of thickness, water quench, cooling to 800–F should occur in 3 minutes.	Subject to intergranular corrosion (at 800––1550–F) in weld and heat affected zone, unless annealed after welding, therefore, strain hardened tempers, i.e., 1/4H, 1/2H, 3/4 & hard are suitable for fusion welding and brazing. Welding materials should be annealed.
303	Austenitic	310	MIL–E–22200 Class 3 AMS 5695	MIL–R–5031 Class 3, AMS 5694	None required if above 60–F.	Anneal after welding. See Heat Treat Data paragraph.	Not recommended for welding however, can be fusion welded to a limited extent but post–weld annealing is required.

Table 4–6. Fusion Welding Characteristics of Corrosion Resisting Steel – General (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	COVERED ELECTRODE	FILLER-WIRE/ ROD	PREHEAT	POSTHEAT-TREAT	
304	Austenitic	308	MIL–E–22200	MIL–R–5031 Class 1	None required if above 60−F.	To restore corrosion resistance and to remove precipitated carbides, heat treat 1850––2000−F, 1/2–1 hr per inch of thickness, and then cool to below 800−F within 3 minutes by quenching in air (Not required for 304L unless subjected to 1200−F for a prolonged period)	Inert gas tungsten arc method is recommended for welding sheet up to 1/8” thick. Shielded metal arc process is preferred for sheet over 1/8” thick. Some sensitization on welding may occur in type 304 especially if metal is over 1/8” thick. Type 304L is susceptible to intergranular corrosion if heated at approximately 1200−F for a long time, however, type 304 is susceptible to intergranular corrosion when heated in 800––1600−F range or welded. Type 304L due to low carbon content (0.03% max) is the recommended grade for welding

Table 4-6. Fusion Welding Characteristics of Corrosion Resisting Steel - General (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	COVERED ELECTRODE	FILLER-WIRE/ ROD	PREHEAT	POSTHEAT-TREAT	
305	Austenitic	308	MIL-E-22200	MIL-R-50 31 Class 1	None required if above 60−F.	To restore corrosion resistance and to remove precipitated carbide, heat treat to 1850− –2000−F 1/2-1 hr per inch thickness and then cool to below 800−F within 3 minutes maximum by quenching in air.	Not generally recommended for welding; reacts similarly to 304 except due to nickel compared to chromium (18-22) it is more susceptible to cracking during cooling.
310	Austenitic	310	MIL-E-22200 Class 3 AMS 5695	MIL-R-5031 Class 3, AMS 5694	None required if above 60−F.	Post annealing required if welded joint is to be exposed to corrosive environment. See Heat Treat Data paragraph for temperature.	Weldable by gas/or electricity preferably by metal arc or inert gas arc methods. Oxy-acetylene is not recommended because of carbon pick-up and resulting adverse effect on corrosion resistance.
314	Austenitic	310	MIL-E-22200 Class 3, AMS 5695	MIL-R-50 31 Class 3 AMS 5694	None required if above 60−F.	Anneal for maximum corrosion resistance. See Heat Treat Data paragraph.	Can be welded by gas or arc methods. Material should be annealed after welding to improve corrosion resistance.

Table 4–6. Fusion Welding Characteristics of Corrosion Resisting Steel – General (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	COVERED ELECTRODE	FILLER-WIRE/ ROD	PREHEAT	POSTHEAT-TREAT	
316 317	Austenitic Austenitic	316	MIL–E–22200	MIL–R–5031 Class 4	None required if above 60–F.	Anneal after welding. See Remarks & General Heat Treat Data paragraph	Subject to stress corrosion and embrittlement when heated at 800– –1600–F for prolonged periods. Low carbon type 316L is normally used for cross sections which cannot be annealed or low temperature stress relieved. Oxyacetylene welding is not advisable for casting because of carbon pick-up and possible impairment of corrosion resistance. Metal arc process is recommended for welding, casting, using lime coated electrodes.

Table 4–6. Fusion Welding Characteristics of Corrosion Resisting Steel – General (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	COVERED ELECTRODE	FILLER-WIRE/ROD	PREHEAT	POSTHEAT-TREAT	
321	Austenitic	347	MIL–E–22200 Class 5, AMS 5681	MIL–R–5031 Class 5, AMS 5680	Same as above.	Postweld anneal not required unless material is over–heated to above 1900−F (See Remarks).	One of the best grades for fabrication of parts by welding. Not subject to intergranular corrosion unless overheated to above 1900−F. Heating at this temperature followed by rapid cooling & reheating at approximately 8000–1500−F will reduce resistance to intergranular attack due to carbide precipitation. For restoration of this sensitized condition, material should be stabilized or fully annealed.

Table 4–6. Fusion Welding Characteristics of Corrosion Resisting Steel – General (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	COVERED ELECTRODE	FILLER-WIRE/ ROD	PREHEAT	POSTHEAT-TREAT	
347 348	Austenitic	347	MIL–E–22200 Class 5, AMS 5681	MIL–R–5301 Class 5, Class 5, AMS 5680	Same as above	Postweld anneal not required unless overheated to above 2150− F for prolonged periods, however, after fabrication a stress relief is recommended.	Primary use is for fabrication of parts by welding without postweld annealing, however, it is harder to fusion weld than 304L. Difficulty may be experienced in welding heavy sections due to cracking. For restoration of sensitized condition, material should be stabilized or fully annealed.

Table 4–6. Fusion Welding Characteristics of Corrosion Resisting Steel – General (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	COVERED ELECTRODE	FILLER-WIRE/ ROD	PREHEAT	POSTHEAT-TREAT	
403 410 416	Martensitic	309 310 410	MIL–E–22200 Class 2/3 AMS 5777 See Remarks	MIL–R–5031 Class 2/3 AMS 5776	300–F	1350–F followed by cool–rate of 100–F per hour maximum to 1100–F is necessary to prevent cracking. Type 416 should be annealed at 1450– after welding to improve ductility & corrosion resistance.	Fusion welding of type 403 & 410 can be accomplished using electrodes of same composition if material is to be heat treated after welding. Type 309/310 electrodes can be used if material is to be used in the as welded condition. 416 is not generally recommended but can be fusion welded to a limited extent. 416 requires annealing after welding to improve both ductility and corrosion resistance.

Table 4–6. Fusion Welding Characteristics of Corrosion Resisting Steel – General (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	COVERED ELECTRODE	FILLER-WIRE/ ROD	PREHEAT	POSTHEAT-TREAT	
420	Martensitic	420 309 310	MIL–E–22200 Class 2/3 See Remarks	MIL–R–5031 Class 2/3	400– – 600– F	1125– – 1400– if possible before material has cooled to 300–F from preheat and welding.	Welding should be restricted to electrical method i.e., shielded metal arc & tungsten arc, etc. Oxyacetylene welding should be avoided to prevent carburizing and resulting loss in corrosion resistance. Type 309/310 electrodes can be used if high strength not required.
422	Martensitic	422	For inert gas method		350– – 400–F	1200– – 1300–F for 8 hrs air cool	Can be welded by metal arc or inert tungsten–arc method.

Table 4–6. Fusion Welding Characteristics of Corrosion Resisting Steel – General (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	COVERED ELECTRODE	FILLER-WIRE/ ROD	PREHEAT	POSTHEAT-TREAT	
440 A B C F	Martensitic	440 309 310	See Remarks	MIL–R–5031 Class 2/3	450−F	1300−F for 4 hrs air cool.	Fusion welding should be accomplished using electrodes of same composition as parent metal when material is heat treated after welding. If a softer weld will meet requirements, such as welding for mechanical bond only, type 309/310 electrodes can be used.
446	Ferritic	446			300−F	1400− –1450−F followed by air cooling/water quench.	Fusion weld using same composition as parent metal. Welding of this type is not recommended for applications subject to high impact. For improvement of ductility in weld area, weld deposit should be peened while at elevated temperature.

Table 4–6. Fusion Welding Characteristics of Corrosion Resisting Steel – General (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		
PH 15–7 MO (AISI 632)		PH 15–7MO PH 15–7MO VM	17–4, AMS 5827, PH15–7MO WPH15–7MO–VM	AMS 5825 AMS 5812 AMS 5812	Not required	Heat treat or anneal.	See 17–7PH except for the following. Inert gas tungsten or fusion welding of annealed and subsequently heat treated material yields a weld of 80–100%. Resistance flash butt welding is not recommended for joints to use in high strength application. The molybdenum additive in this alloy causes larger amounts of deltaferrite or free ferrite to form in the weld deposit upon solidification. The amount of ferrite requires some control in order to maintain good ductility in the highest HT conditions. This control can be accomplished by the use of filler metal of appropriate chemical composition, through heat treatment, or both.

Table 4–6. Fusion Welding Characteristics of Corrosion Resisting Steel – General (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	COVERED ELECTRODE	FILLER-WIRE/ ROD	PREHEAT	POSTHEAT-TREAT	
17–4PH	Martensitic This alloy is Austenitic at elevated temperature but transforms to Martensitic upon cooling.		17–4PH AMS 5827	AMS 5825	Not required.	Heat treat or anneal.	Readily weldable using arc and resistance welding processes commonly used with Austenitic stainless steels. Sound welds with properties comparable to parent metal can be obtained using weld metal of same composition and post weld annealing or heat treating. Spot welding and seam welding readily accomplished using procedures similar to those used for austenitic stainless. Best results obtained in partly or fully heat treated conditions. Resistance butt welding not currently recommended.

Table 4–6. Fusion Welding Characteristics of Corrosion Resisting Steel – General (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	COVERED ELECTRODE	FILLER-WIRE/ ROD	PREHEAT	POSTHEAT-TREAT	
17–7PH	Austenitic in condition A. Heat treated conditions are martensitic with some austenitic.		17–7PH AMS 5827 17–4PH	AMS 5825	Not required.	Heat treat or anneal. Fusion welded joints using 17–4PH electrode can be heat treated to 170 KSI ultimate tensile by austenitic conditioning at 1400–followed by age hardening at 950–F. Slightly higher strength may be obtained by austenitic conditioning at 1600–F and age hardening at 900–F.	Fusion welding and spot welding can be readily accomplished. Best results are obtained by spot welding partial or fully heat treated material. The surface to be welded should be cleaned by vapor or sandblasting to avoid porous welds. Inert gas tungsten arc of annealed and subsequently heated metal yields a weld of 95% efficiency. Welding of TH1050 yields a weld of 65% efficiency. Copper chill blocks with grooves should be used to inert back side of weld. In condition A 17–7PH alloy is primarily austenitic containing 5–20 ferrite.

Table 4–6. Fusion Welding Characteristics of Corrosion Resisting Steel – General (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	COVERED ELECTRODE	FILLER-WIRE/ ROD	PREHEAT	POSTHEAT-TREAT	
19–9 DL 19–9 DX	Austenitic		19–9WX 19–9WMO MIL–E–16715 Class 19 AMS 5785	AMS 5782 MIL–R–5031 Class 6	None re–quired.	Stress relieve at 1200−F minimum & preferably full annealed at 1800−F air cool.	Heating should be accomplished in a neutral or slightly oxidizing atmosphere.
AM350		AM350 AM355 308 309	AMS 5775 AMS 5781 MIL–E–22200/2 MIL–E–22200/2	AMS 5774 AMS 5780 C11 MIL–R–5031 C12	Not re–quired.	To heat treat to condition SCT, use same full heat treatment as for unwelded material. When age hardening to condition DA subsequent annealing to condition L is not required, if AM350 weld metal is used. If AM 355 filler metal is used however, annealing to condition L should precede the condition DA aging treatment.	Weldable by using same procedures as those used for austenitic stainless steel, it is easier to weld than ferritic or martensitic steel and preheating or post weld heating not required. This material remains ductile during cooling although structure changes from austenitic to 15% martensite. Welding can be accomplished in all conditions. The recommended technique for welding the principal forms are electric resistance, tungsten electrode and consumable electrode inert gas welding.

Table 4–6. Fusion Welding Characteristics of Corrosion Resisting Steel – General (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	COVERED ELECTRODE	FILLER-WIRE/ ROD	PREHEAT	POSTHEAT-TREAT	
AM350 (Cont.)							Where high strength is not required 308/309 electrode and filler wire may be used. Heat treated welds having 90–100% joint efficiency in light gage metal can be obtained without filler metal. AM350 or AM355 electrode/wire shall be used for heavier gages.

Table 4–6. Fusion Welding Characteristics of Corrosion Resisting Steel – General (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	COVERED ELECTRODE	FILLER-WIRE/ ROD	PREHEAT	POSTHEAT-TREAT	
AM355		308 309 310 Remarks		Not required, alloy is highly resistant to weld cracking.	Not required, alloy is highly resistant to weld cracking.	See Remarks and heat treat data post heating not required.	Bar, plate and forgings are normally welded with filler metal in all conditions. Where joint strength is not important any austenitic (18–8) steel filler rod or electrode may be used. Welds heat treated to condition SCT/ DA approaching 100% efficiency can be obtained with AM355, filler metal. Fusion welding of condition CRT and SCCRT destroys the effect of cold rolling as well as heating above 900–F.

Table 4–7. Fusion Welding Characteristics of Nickel–Chromium–Iron and Nickel Alloys

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	COVERED ELECTRODE	FILLER WIRE/ ROD	PREHEAT	POSTHEAT-TREAT	
Inconel Alloy 600		“62” Inconel ”42” Inconel		MIL–R–5031 CL 8A AMS 5679 MIL–R–5031 CL 8 MIL–R–5683			This alloy is readily weldable with high joint efficiency. Inconel ”62” welding wire is recommended for inert gas method and tungsten arc. Inconel ”42” is recommended where inert gas is not used. When gas welding a slight reducing flame should be used.
Inconel 718		Inconel 718		AMS 5832	Anneal 1900– – l950–F (OPT)	Stress relieve 1700–F 1 hr, air cool, then 1325–F 16 hrs. air cool. Age (Opt) 1325–F 8 hrs. furnace cool to 1150–F and hold for 18 hrs. air cool.	The alloy may be welded in the annealed or aged condition. If welded in the aged condition the heat affected zone will be softer than that of the parent metal.

Table 4–7. Fusion Welding Characteristics of Nickel–Chromium–Iron and Nickel Alloys (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	COVERED ELECTRODE	FILLER WIRE/ ROD	PREHEAT	POSTHEAT-TREAT	
Inconel 625		Inconel 625		AMS 5837			Alloy is readily welded by the gas shielded arc processes with either a tungsten electrode (GTAW) or a consumable electrode (GMAW) of Inconel filler metal 625.
Inconel “X”		”69” Inconel		MIL–R–503l CL 14	Severely cold worked material should be stress relieved at 1500–F 8 hours with part being rapidly brought up to heat.	After stress relieving welded assembly should be aged at 1300–F, 20 hours.	This alloy can be fusion welded by various methods and resistance welded. Fusion welding of Inconel X should be confined to annealed or cold worked material. The tungsten arc & gas shielded methods using Inconel X welding wire can be used to weld these conditions.

Table 4–7. Fusion Welding Characteristics of Nickel–Chromium–Iron and Nickel Alloys (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	COVERED ELECTRODE	FILLER WIRE/ ROD	PREHEAT	POSTHEAT-TREAT	
Inconel “X” (Cont.)							Welding of aged material without cracking is only possible by the safe end method of adding Inconel X sections before heat treating and then welding the safe ends together with Inconel.
Hastelloy C		Hastelloy C		MIL–R–503l CL 11 MIL–R–5031 CL 12 (See remarks) MIL–R–5031 CL 3 (See remarks)	Casting should be preheated to l200––1400–F.	See remarks.	Alloy can be welded by all conventional methods. However, the oxyacetylene method is not recommended for parts to be used in corrosive applications because of carbon pickup. Weldability of this alloy is similar to that of austenitic stainless steel. The following measures are required for fusion welding:

Table 4-7. Fusion Welding Characteristics of Nickel-Chromium-Iron and Nickel Alloys (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	COVERED ELECTRODE	FILLER WIRE/ ROD	PREHEAT	POSTHEAT-TREAT	
Hastel-loy C (Cont.)							a. Keep weld restraint at a minimum. b. Hold heat affected zone narrow and parent metal as cool as possible when welding wrought products. c. Maintain alignment. d. Use string beads. The same analysis filler metal should be used to join two pieced of the alloy. Type 310 stainless or Hastelloy W (wire or electrode) are recommended for joining other metals.
Hastel-loy X		Hastel-loy X	AMS 5799	AMS 5790	Not required		Alloy can be welded by most common welding methods.

Table 4–7. Fusion Welding Characteristics of Nickel–Chromium–Iron and Nickel Alloys (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		
Hastelloy X (Cont.)							Fusion welding of cold worked material will result in a weld strength equal to that of annealed metal. Fusion welding may be accomplished by metallic are, inert gas shielded are, submerged melt and sigma methods. Welding should be done in a flat position as fluidity as the alloy makes position welding difficult. Welds in this alloy retain good ductility. Resistance welding requires special control; long dwell times with water cooling are recommended to avoid coring or crystal segregation and to develop a full nugget. For seam welding an intermittent drive is recommended to prevent cracking and excessive distortion.

Table 4–7. Fusion Welding Characteristics of Nickel–Chromium–Iron and Nickel Alloys (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		
Monel 1K500		Nr44K Monel Nr30K Monel				See remarks.	This alloy can be welded by oxyacetylene, inert–gas tungsten arc, or metallic arc processes using proper filler rod. For oxy–acetylene welding use Nr44K Monel gas welding wire with a paste flux. The oxyacetylene flame should be reducing and heated end of filler rod should be kept in the protecting atmosphere of the flame to avoid oxidizing the rod. For metallic arc welding, use Nr–34K Monel. Welding should be performed on annealed material and the welded assembly should be stress relieved before aging. Welded assembly should be taken through the age hardening range quickly.

Table 4–7. Fusion Welding Characteristics of Nickel–Chromium–Iron and Nickel Alloys (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	COVERED ELECTRODE	FILLER WIRE/ ROD	PREHEAT	POSTHEAT-TREAT	
Rene 4l		RENE 4l Hastelloy		AMS 5800 MIL–R–5031 CL l2	Not required.	See remarks.	Alloy can be fusion welded if copper and gas backing with a tight hold down is used. Start and finish should be made on metal tabs of the same thickness using inert gas atmosphere of 2 parts helium to 1 part argon. This reduces the current input which should be held as low as possible. The use of the tab reduces heat input which should be held as low as possible to minimize the heat affected zone. Following the torch with a water spray reduces the hardness and produces maximum ductility in the weld and weld affected zones.

Table 4–7. Fusion Welding Characteristics of Nickel–Chromium–Iron and Nickel Alloys (Cont.)

ALLOY/DESIGN		RECOMMENDED FILLER MATERIAL/SPEC			HEAT TREATMENT		REMARKS
TYPE	STRUCTURE MATERIAL	TYPE	COVERED ELECTRODE	FILLER WIRE/ ROD	PREHEAT	POSTHEAT-TREAT	
Rene 41 (Contd.)							If possible, solution heat treatment should follow welding. When solution heating high stress welds, heating and cooling rates through the aging range (1200––1600–F should be high. Hastelloy ”W” filler material can be used when joining the alloy with itself or other age hardenable nickel–base alloys.

Table 4–8. Suggested Filler Material For Various Aluminum Alloys[1]

Base Metal	Filler Alloys	
	Preferred for Maximum As–Welded Tensile Strength	Alternate Filler Alloys For Maximum Elongation
1350	1100	1350/1260
1100	4043/1100	1100
2014	4115	4043/2319[4]
2024	4145	4043/2319[4]
2219	2319	2319[4]
3003	5356	1100/4043
3004	5554	5356
5005	5356/4043	5356
5050	5356	5356
5052	5356	5653
5083	5183	5183
5086	5356/5183	5183
5154	5356	5356
5357	5554	5356
5454	5554	5356
5456	5556	5356
6061	4041/5356[2]	5356[3]
6063	4043/5356[2]	5356[3]
7005	5356	5356
7039[3]	5356	5356

(1) The above table shows recommended choices of filler alloys for welds requiring maximum mechanical properties. Selected alloys are based on tests conducted by Kaiser Aluminum. Different filler metals may be required for special service, such as immersion in fresh or salt water, hydrogen peroxide and certain other chemical exposures or sustained elevated temperatures (above 150–F). Plate materials containing over 3% magnesium should not be used for prolonged service above 150–F. Weld metal which has been cold worked by forming or other means should not be used for prolonged service above 150–F. For all special services of welded aluminum, inquiry should be made of your supplier.

(2) When making welded joints in 606l or 6063 electrical conductor in which maximum conductivity is desired, use 4043 filler metal. However, if strength and conductivity both are required, 5356 filler may be used and the weld reinforcement increased in size to compensate for the lower conductivity of the 5356 filler metal.

(3) For armor plate only.

(4) Low ductility of weldment is not appreciably affected by filler used. Plate weldments in these base metal alloys generally have lower elongations than those of other alloys listed in this table.

Table 4–9. Welding Rods For Joining Wrought to Wrought Alloy (Magnesium)

BASE ALLOY	A3A	AZ31B	AZ61A	AX80A	HK31A	HM31A	ZK21A	ZK60A&B
A3A	1							
AZ31B	1	1						
AZ61A	1	1	1					
AZ80A	1	1	1	1				
HK31A	1	1	1	1	2			
HM21A	1	1	1	1	2	2		
HM31A	1	1	1	1	2	2	2	
ZK21A	1	1	1	1	1	1	1	1
ZK60A, B	X	X	X	X	X	X	X	X

CODE 1 = Use AZ92A or AZ61A rod – AZ92A preferred. AZ61A cheaper, generally satisfactory, but subject to weld cracking.

2 = Use EZ33A rod, particularly when two alloys for elevated temperature use are to be welded. Use AZ92A or AZ61A when elevated and room temperature alloy are welded together.

X = Welding not recommended.

Table 4–10. Welding Rods For Joining Cast To Wrought Alloys (Magnesium)

CAST ALLOY	A3A	AZ31B	AZ61A	AZ80A	HK31A	HM21A	HM31A	ZK21A	ZA60A&B
AZ63A	X	X	X	X	X	X	X	X	X
AZ81A	1	1	1	1	1	1	1	1	X
AZ91C	1	1	1	1	1	1	1	1	X
AZ92A	1	1	1	1	1	1	1	1	X
EZ33A	1	1	1	1	2	2	2	1	X
HK31A	1	1	1	1	2	2	2	1	X
HZ32A	1	1	1	1	2	2	2	1	X
KIA	1	1	1	1	1	1	1	1	X
QE22A	1	1	1	1	2	2	2	1	X
ZE41A	1	1	1	1	1	1	1	1	X
ZH62A	X	X	X	X	X	X	X	X	X
ZK51A	X	X	X	X	X	X	X	X	X

CODE 1 = Same as for Table 4–9
2 = Same as for Table 4–9
X = Same as for Table 4–9

Table 4–11. Welding Rods For Joining Cast To Cast Alloys (Magnesium)

CAST ALLOYS	AZ63A	AZ81A	AZ91C	AZ92A	EZ33A	HK31A	HZ32A	KIA	QE22A	ZE41A	ZH62A ZK51A
AZ63A	1										
AZ81A	X	1									
AZ91C	X	1	1								
AZ92A	X	1	1	1							
EZ33A	X	1	1	1	2						
HK31A	X	1	1	1	2	2					
HZ32A	X	1	1	1	2	2	2				
KIA	X	1	1	1	1	1	1	2			
QE22A	X	1	1	1	2	2	2	1	2		
ZE41A	X	1	1	1	1	1	1	1	1	2	
ZH62A	X	X	X	X	X	X	X	X	X	X	X
ZK51A	X	X	X	X	X	X	X	X	X	X	X

Table 4–12. Welding Characteristics (Titanium)

MATERIAL	FILLER METAL	REMARKS
Unalloyed Commercially Spec Comp A, Band C	Commercially Pure AMS 4951	Stress Relieve after welding; resistance (spot and seam) may be accomplished without protective atmosphere.
4A1–4Mn	Not recommended for welding.	
4A1–3Mo–1V	6Al–4V (AMS4954 3Al or AMS 4951)	For resistance welding use technique similar to those used for austenitic stainless steels.
5Al–1.5Cr–l.5Fe–1Mo 6A1–6V–2Sn	Not currently recommended for welding, however, procedures under development.	
5Al–2.75Cr–l.25Fe	Fusion welding not recommended.	Spot welding can be satisfactorily accomplished.
5Al–2.5Sn	5A1–2.5Sn AMS 4953 3A1, or commercially pure AMS4951.	Fusion welding by the heli–arc method is recommended for welding. Also readily weldable by spot and seam methods. Welds have good ductility and mechanical properties comparable to base metal. Difficulty may be experienced from porosity after welding.

Table 4–12. Welding Characteristics (Titanium) (Cont.)

MATERIAL	FILLER METAL	REMARKS
5Al–5Sn–5Zr		Alloy has good properties in welded condition. Improvement in properties can be achieved by post weld stress relief annealing. Readily weldable by resistance methods. Under most conditions of exposure to elevated temperatures, loss of strength of spot welds is lower than parent metal.
7Al–l2Zr		Only limited data available. Present data indicates fusion and resistance welding is readily accomplished by use of technique common to other titanium alloys. Fusion welds are somewhat more notch sensitive than parent metal. Stress relieving at 1300–F, 3/4 hr recommended to minimize stress corrosion cracking; avoid stress relieving at 1200–F or below.
8A1–2Cb–1T2		Current data indicates alloy readily weldable with same techniques used for unalloyed titanium.
2Cr–2Fe–2Mo	Not recommended for welding, because brittle when cooled.	
8Mn	Not recommended for welding.	
3A1–13V–11Cr	3A1–13V–l1Cr	Can be satisfactorily welded using inert–gas–shielded tungsten arc without filler or with consumable filler electrode. Also, it can be seam and spot welded.
6Al–4V	6Al–4V AMS 4954, 3A1, or commercially pure AMS 4951.	Weldments have lower ductility than parent metal, however, useful fusion and resistant welds can be made with proper precautions. Complete inert gas shielded required for either tungsten arc or consumable electrode fusion welds. Resistance welding is accomplished by technique similar to those used for austenitic stainless steels.

Table 4–12. Welding Characteristics (Titanium) (Cont.)

MATERIAL	FILLER METAL	REMARKS
7A1–4Mo	See 6Al–4Mo.	
8A1–1Mo–1V		Only limited data available. Fusion and resistance welding of sheet accomplished using technique common to other titanium alloys. Stress relief recommended after welding.

Table 4–13. Amperage Variations

CATEGORY I
(DC, straight polarity)

Thickness	Amperage
to 0.045 inch	30–40
0.045–0.065 inch	40–65
0.065–0.090 inch	60–100
over 0.090 inch	60–120 (multipass)
castings	50–150

CATEGORY III
(AC, high frequency)

Thickness	Amperage
to 0.045 inch	30–100
0.045–0.065 inch	50–150
0.065–0.080 inch	125–220

CATEGORY II
(DC, straight polarity)

to 0.045 inch	35–45
0.045–0.060 inch	50–60
0.060–0.080 inch	60–85
0.080–0.100 inch	80–105
0.100–0.125 inch	90–150
0.125 inch and over	90–150(multipass)
castings	50–150

CATEGORY IV
(DC, straight polarity)
–Titanium

to 0.045 inch	40–50
0.045–0.064 inch	60–70
0.065–0.090 inch	70–95
over 0.090 inch	70–95
castings	50–150

SECTION V.
WELDING AND CUTTING EQUIPMENT

5.1 WELDING AND CUTTING EQUIPMENT.

5.1.1 Oxyacetylene Welding Equipment.

5.1.1.1 General. The equipment used for oxyacetylene welding consists of a source of oxygen and a source of acetylene from a portable or stationary outfit, two regulators, two lengths of hose with fittings, a welding torch with a cutting attachment or a separate cutting torch. In addition, suitable goggles for eye protection, gloves to protect the hands, a method to light the torch, and wrenches for the various connections on the cylinders, regulators, and torches are required.

5.1.1.2 Stationary Welding Equipment.

a. General. This equipment is installed where welding operations are conducted in a fixed location. Oxygen and acetylene are provided in the welding areas outlined in b and c below.

b. Oxygen. The oxygen is obtained from a number of cylinders manifolded and equipped with a master regulator to control the pressure and the flow (figure 5-1). The oxygen is supplied to the welding stations through a pipe line equipped with station outlets (figure 5-2).

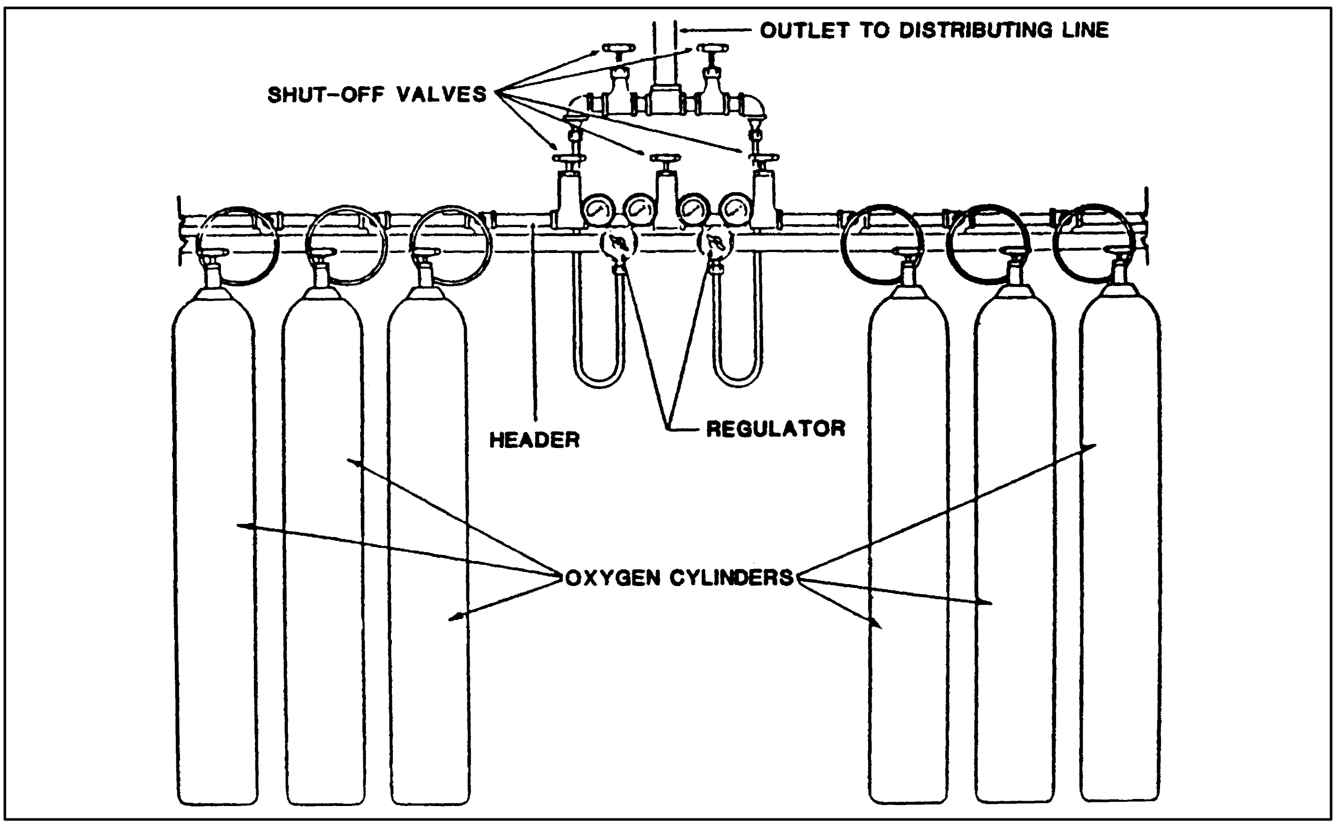


Figure 5-1. Stationary Oxygen Cylinder Manifold and Other Equipment

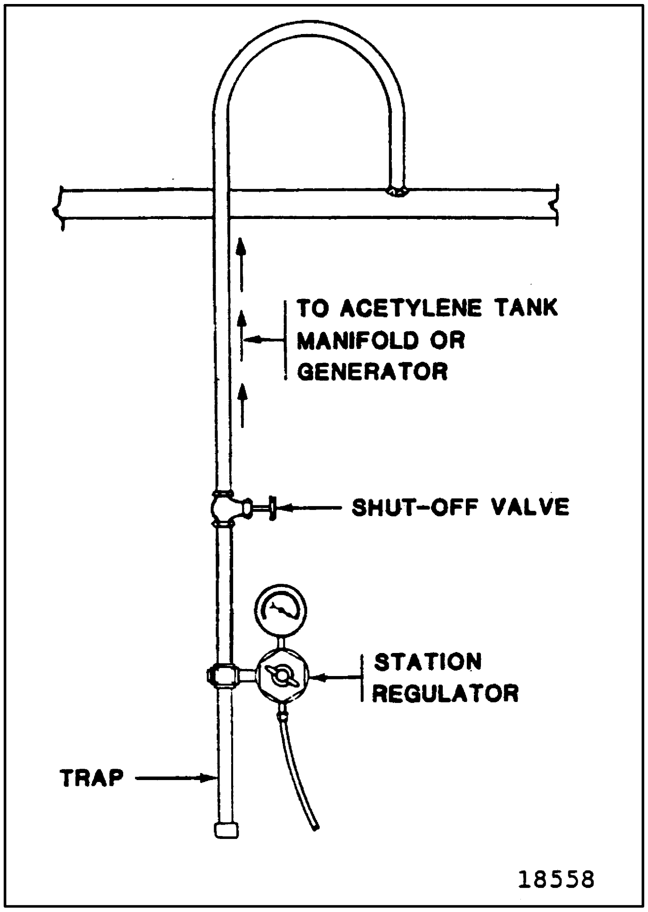


Figure 5–2. Station Outlet for Oxygen or Acetylene

c. Acetylene. The acetylene is obtained from acetylene cylinders set up as shown in figure 5–3. The acetylene is supplied to the welding stations through a pipe line equipped with station outlets as shown in figure 5–2.

5.1.1.3 Portable Welding Equipment. The portable oxy-acetylene welding outfit consists of an oxygen cylinder and an acetylene cylinder with attached valves, regulators, gages, and hose (figure 5–4). This equipment may be temporarily secured on the floor, or mounted in a two wheel all welded steel truck equipped with a platform which will support two large cylinders. The cylinders are secured by chains attached to the truck frame. A metal toolbox, welded to the frame, provides storage space for torch tips, gloves, fluxes, goggles, and necessary wrenches.

5.1.1.4 Acetylene Cylinders.

a. Acetylene is a compound of carbon and hydrogen (C2H2). It is a versatile industrial fuel gas used in cutting, heating, welding, brazing, soldering, flame hardening, metallizing and stress relieving applications. It is produced when calcium carbide is submerged in water or from petrochemical process. The gas from the acetylene generator is then compressed into cylinders or fed into a piping system. Acetylene can become unstable when compressed in its gaseous state above (15) PSIG and therefore cannot be stored in a hollow cylinder under high pressure the way other gases are stored. Acetylene cylinders are filled with a porous material creating in effect a ”solid” as opposed to a ”hollow” cylinder. The porous filling is then saturated with liquid acetone. When acetylene is pumped into the cylinder it is absorbed by the liquid acetone throughout the porous filling and is held in a stable condition (see figure 5–5). Acetylene cylinders must never be transfilled. Acetylene cylinders are available in capacities of 10, 40, 60, 75, 100, 130, 190, 225, 290, 300, 330, 360 and 390 cubic feet.

b. The acetylene cylinders are equipped with safety plugs (figure 5–5) having a small hole through the center. This hole is filled with a metal alloy which melts at approximately 212_F (100–C) or releases at 500 psi. When a cylinder is overheated the plug will melt and permit the acetylene to escape before a dangerous pressure can build up. The plug hole is too small to permit a flame to burn back into the cylinder if the escaping acetylene should become ignited.

c. The brass acetylene cylinder valves have squared stainless steel valve stems which can be fitted with a cylinder wrench and opened or closed when the cylinder is in use. The outlet of the valve is threaded for connection to an acetylene pressure regulator by means of a union nut. The regulator inlet connection gland fits against the face of the threaded cylinder connection and the union nut draws the two surfaces together. Whenever the threads on the valve connections are damaged to a degree that will prevent proper assembly to the regulator, the cylinder should be marked and set aside for return to the manufacturer.

d. A protective metal cap (figure 5–5) screws onto the valve to prevent damage during shipment or storage.

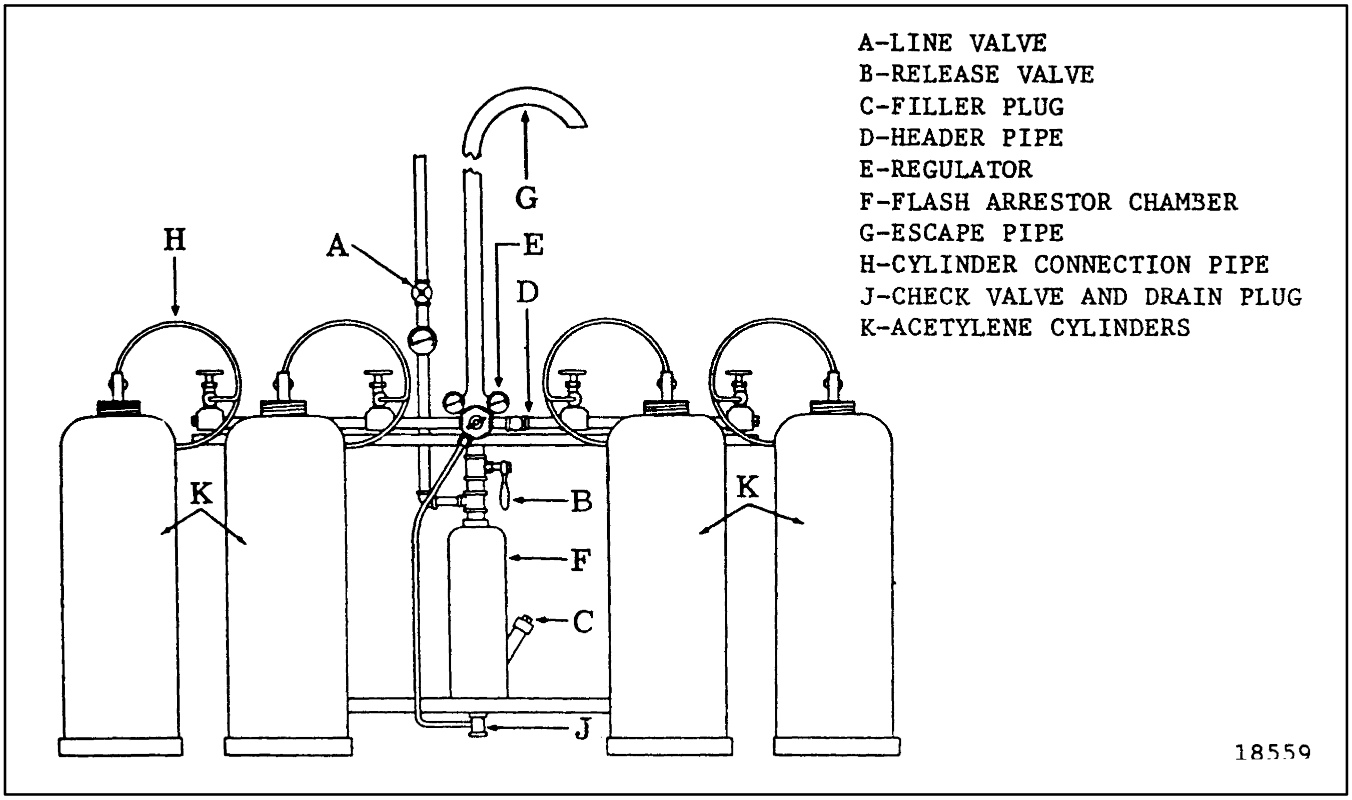


Figure 5–3. Stationary Acetylene Cylinder Manifold and Other Equipment

WARNING

All acetylene cylinders should be checked with a soap solution for leakage at the valves and safety fuse plugs. Leaking acetylene could accumulate in the storage room or other confined spaces and become a fire and explosion hazard.

5.1.1.5 Oxygen and its Production.

a. General. Oxygen is a colorless, tasteless, and odorless gas that is slightly heavier than air. It is nonflammable but will support combustion with other elements. In its free state oxygen is one of the most common elements. The atmosphere is made up of approximately 21 parts of oxygen and 78 parts of nitrogen, the remainder being rare gases. Rusting of ferrous metals, discoloration of copper, and the corrosion of aluminum are all due to the action of atmospheric oxygen. This action is known as oxidation.

b. Production of oxygen.

(1) Oxygen is obtained commercially either by the liquid air process or by the electrolytic process.

(2) In the liquid air process air is compressed and cooled to a point where the gases become liquid. As the temperature of the liquid air is raised nitrogen in a gaseous form is given off first, since its boiling point is lower than that of liquid oxygen. These gases, having been separated, are then further purified and compressed into cylinders for use.

(3) In the electrolytic process water is broken down into hydrogen and oxygen by the passage of an electric current. The oxygen collects at the positive terminal and the hydrogen at the negative terminal. Each gas is collected and compressed into cylinders for use.

c. Oxygen Cylinders. A typical oxygen cylinder is shown in figure 5–6. It is made of steel and has a capacity of 220 cubic feet at a pressure of 2,000 psi and a temperature of 70–F (21–C). The attached equipment provided by the oxygen supplier consists of an outlet valve, a removable metal cap for the protection of the valve during shipment or storage, and a low melting point safety fuse plug and disk.

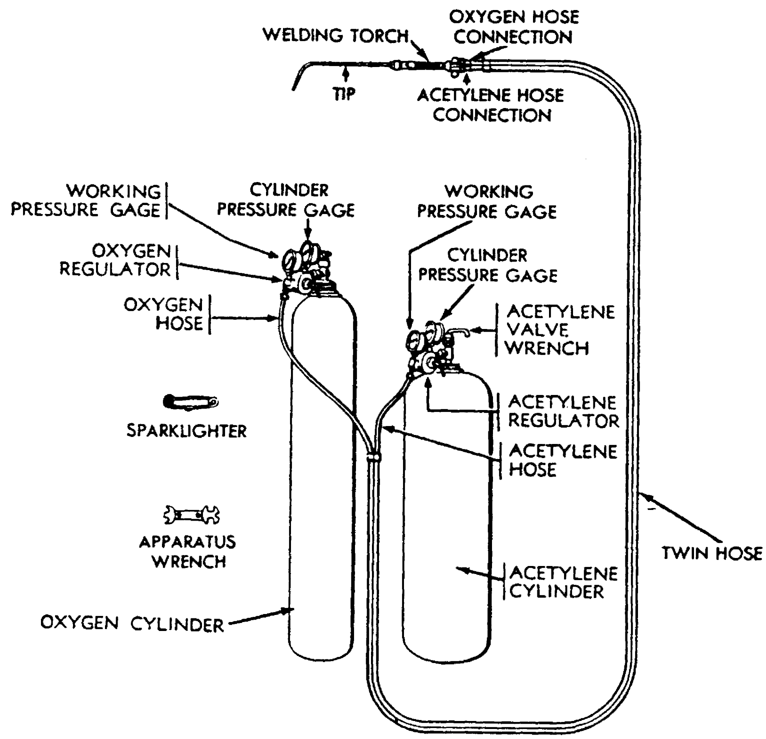


Figure 5-4. Portable Oxyacetylene Welding and Cutting Equipment

5.1.1.6 Oxygen and Acetylene Regulators.

a. General. The gases compressed in oxygen and acetylene cylinders are at pressures too high for oxyacetylene welding. Regulators are necessary to reduce pressure and control the flow of gases from the cylinders. Most regulators in use are either the single stage or the two stage type. Check valves should be installed between the torch hoses and their respective regulators to prevent flashback through the regulators.

b. Single Stage Oxygen Regulator. The mechanism of a single stage oxygen regulator (figure 5-7) has a nozzle through which the high pressure gas passes, a valve seat to close off the nozzle, and balancing springs. Some types have a relief valve and an inlet filter to exclude dust and dirt. Pressure gages are provided to show the pressure in the cylinder or pipe line and the working pressure. In operation the working pressure falls as the cylinder pressure falls. For this reason the working pressure must be adjusted at intervals during welding operations. The oxygen regulator controls and reduces the oxygen pressure from any standard commercial oxygen cylinder containing pressures up to 3,000 psi. The high pressure gage, which is on the inlet side of the regulator, is graduated from 0 to 3,000 psi. The low pressure gage which is on the outlet side of the regulator, is graduated from 0 to 500 psi.

c. Operation of Single Stage Oxygen Regulator.

(1) The oxygen enters the regulator through the high pressure inlet connection and passes through a glass wool filter which removes dust and dirt. The seat which closes off the nozzle is not raised until the adjusting screw is turned in. Turning in the adjusting screw applies pressure to the adjusting spring which bears down on the rubber diaphragm. The diaphragm presses downward on the stirrup and overcomes the pressure on the compensating spring. When the stirrup is forced downward the passage through the nozzle is opened, and oxygen is allowed to flow into the low pressure chamber of the regulator. From here the oxygen passes through the regulator outlet and the hose to the torch. A certain set pressure must be maintained in the low pressure chamber of the regulator so that oxygen will continue to be forced through the orifices of the torch, even if the torch needle valve is open. This pressure is indicated on the working pressure gage of the regulator and depends on the position of the regulator adjusting screw. The pressure is increased by turning the adjusting screw to the right and decreased by turning this screw to the left.

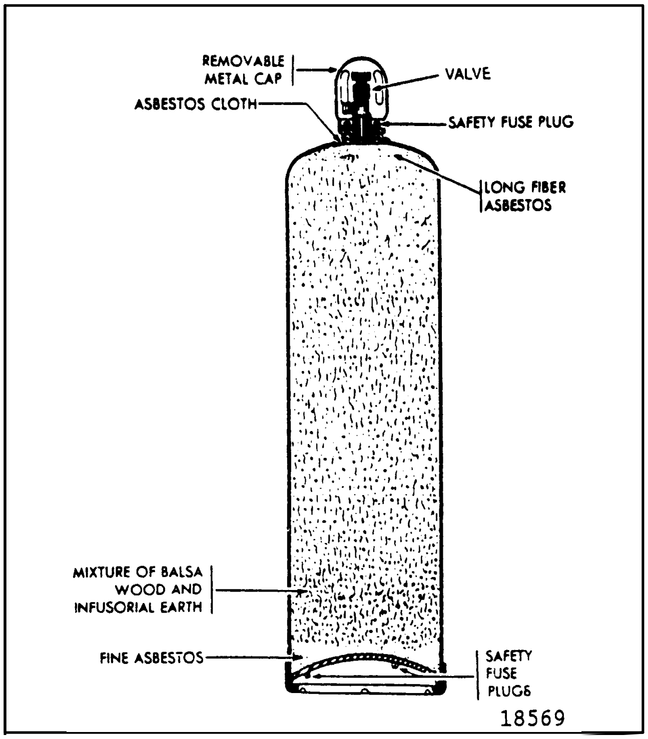


Figure 5–5. Acetylene Cylinder Construction

(2) Regulators used at stations to which gases are piped from an oxygen manifold, acetylene manifold, or acetylene generator have only one low pressure gage because the pipe line pressures are usually set at 15 psi for acetylene and approximately 200 psi for oxygen.

d. Two Stage Oxygen Regulator. The operation of the two stage regulator (figure 5–8) is similar in principle to that of the single stage regulator. The difference is that the total pressure decrease takes place in two steps instead of one. On the high pressure side the pressure is reduced from cylinder pressure to intermediate pressure. On the low pressure side the pressure is reduced from intermediate pressure to working pressure. Because of the two stage pressure control the working pressure is held constant, and pressure adjustment during welding operations is not required.

e. Acetylene Regulator. This regulator controls and reduces the acetylene pressure from any standard commercial cylinder containing pressures up to and including 500 psi. It is of the same general design as the oxygen regulator but will not withstand such high pressures. The high pressure gage, on the inlet side of the regulator, is graduated from 0 to 500 psi. The low pressure gage, on the outlet side of the regulator, is graduated from 0 to 30 psi. Acetylene should not be used at pressures exceeding 15 psi.

5.1.1.7 Oxyacetylene Welding Torch.

a. General. The oxyacetylene welding torch is used to mix oxygen and acetylene in definite proportions and to control the volume of these gases burning at the welding tip. The torch has two needle valves, one for adjusting the flow of oxygen and one for adjusting the flow of acetylene. In addition, there are two tubes, one for oxygen, the other for acetylene; a mixing head; inlet nipples for the attachment of hoses; a tip; and a handle. The tubes and handle are of seamless hard brass, copper–nickel alloy, stainless steel, or other noncorrosive metal of adequate strength. The tips, which are available in different sizes, are described in paragraph 5.1.1.8.

b. Types of Torches.

(1) There are two general types of welding torches; the low pressure or injector type, and the equal pressure type.

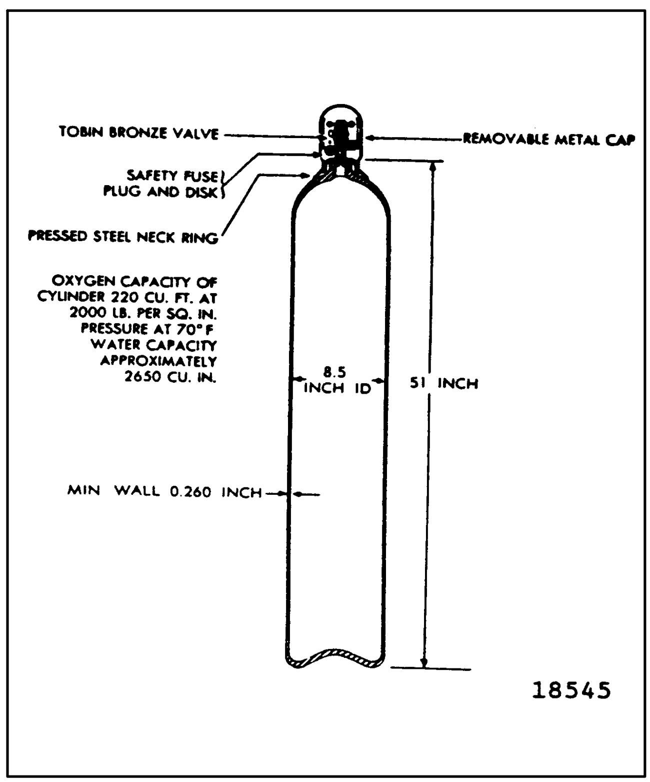


Figure 5–6. Oxygen Cylinder Construction

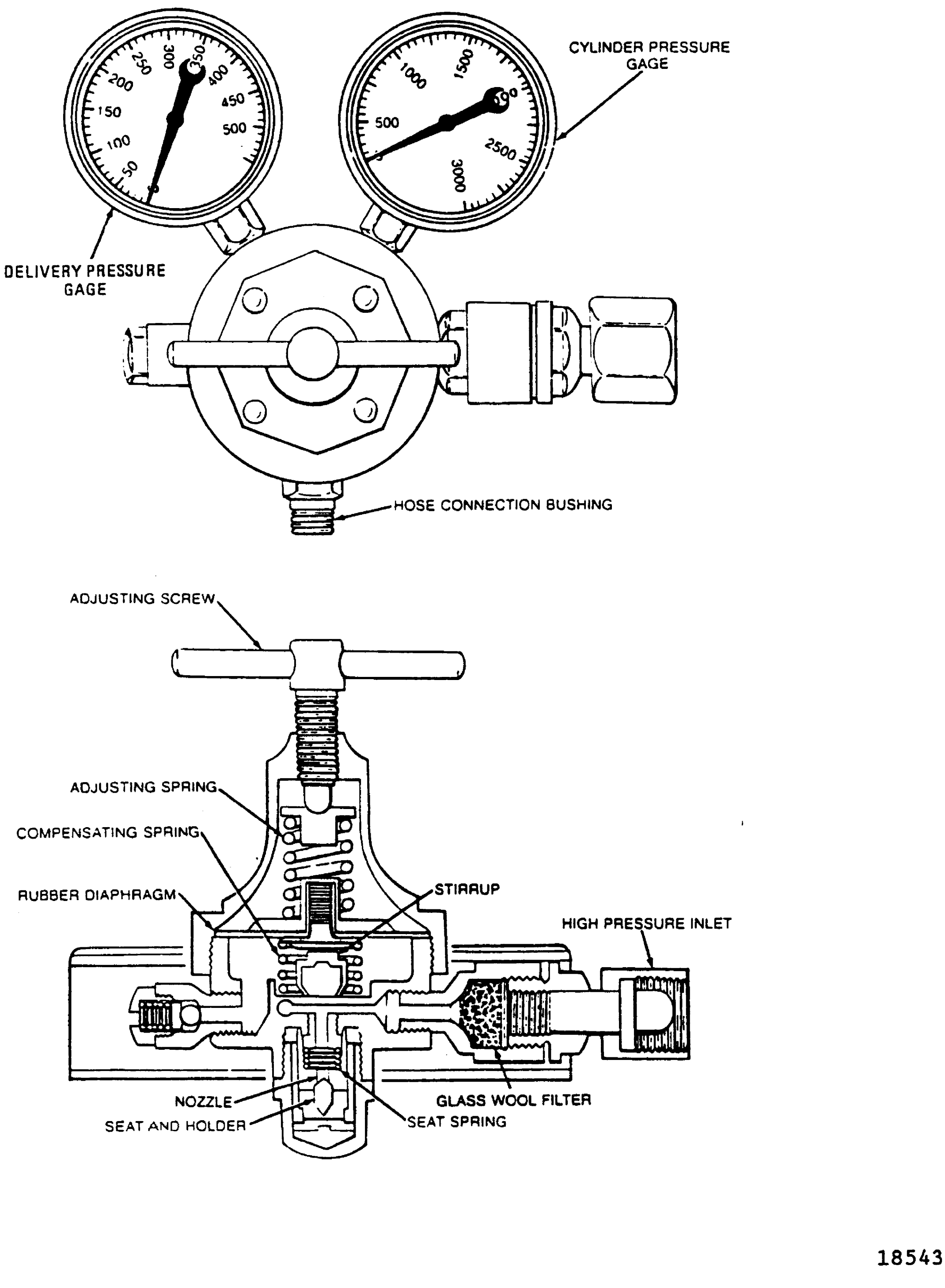


Figure 5–7. Single Stage Oxygen Regulator

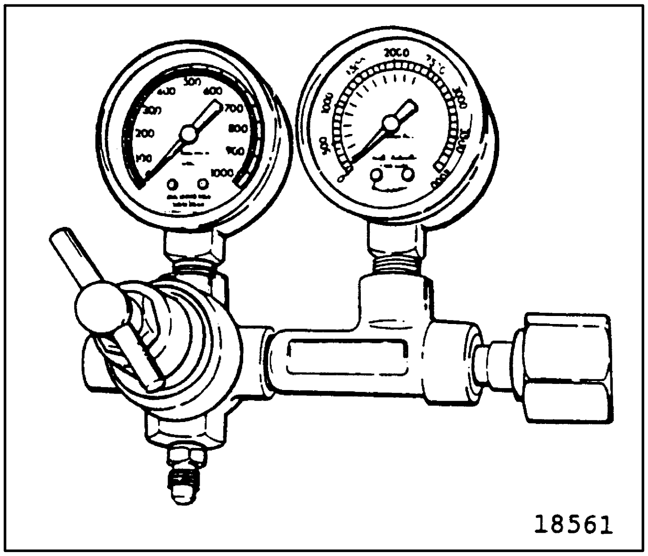


Figure 5–8. Two Stage Oxygen Regulator

(2) In the low pressure or injector type (figure 5–9) the acetylene pressure is less than l psi. A jet of high pressure oxygen is used to produce a suction effect to draw in the required amount of acetylene. This is accomplished by designing the mixer in the torch to operate on the injector principle. The welding tips may or may not have separate injectors designed integrally with each tip.

(3) The equal pressure torch (figure 5–10) is designed to operate with equal pressures for the oxygen and acetylene. The pressure ranges from l to 15 psi. This torch has certain advantages over the low pressure type in that the flame desired can be more readily adjusted, and since equal pressures are used for each gas the torch is less susceptible to flashbacks.

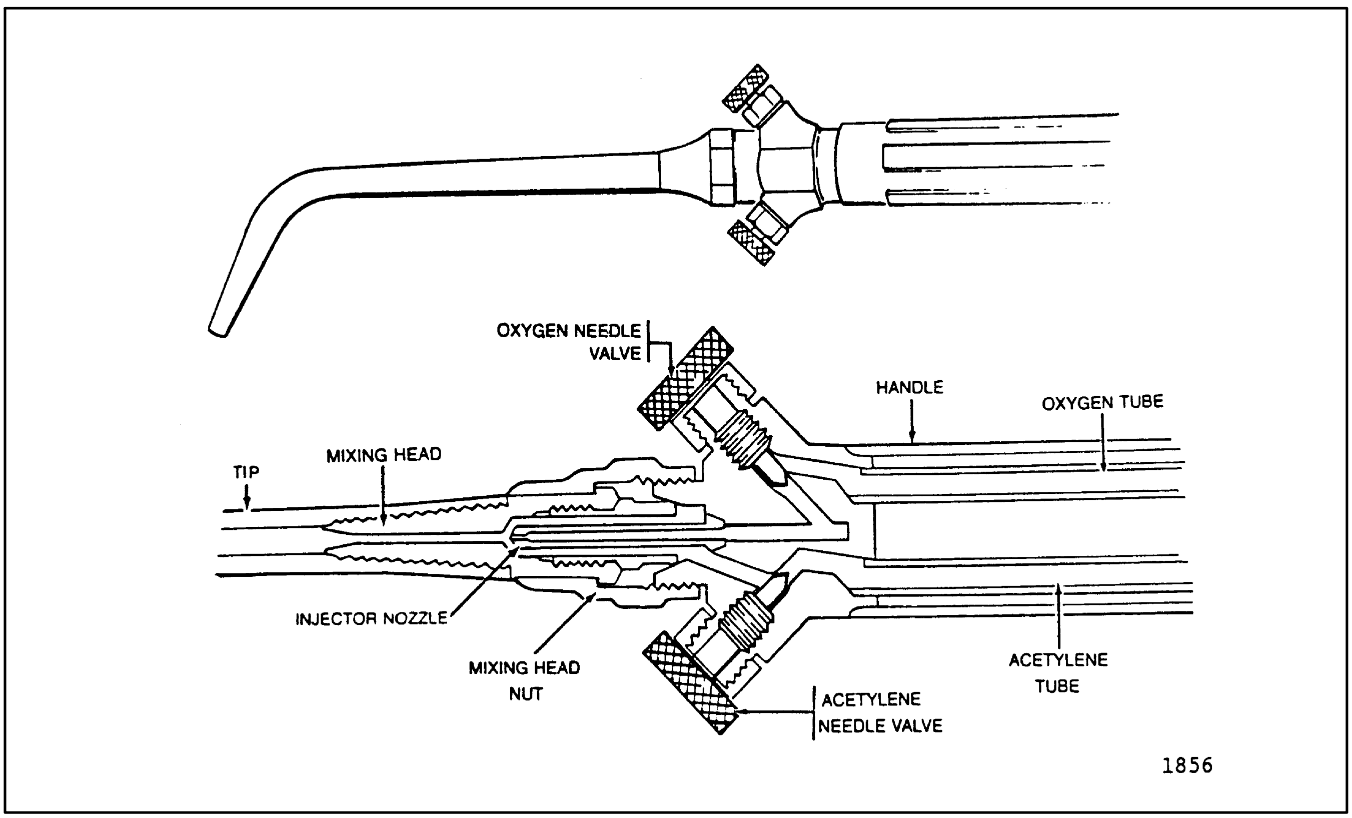


Figure 5–9. Mixing Head for Injector Type Welding Torch

5.1.1.8 Welding Tips and Mixers.

a. Welding and cutting tips, such as the one shown in figure 5–11, are made of hard drawn electrolytic copper or 95 percent copper and 5 percent tellurium. They are made in various styles and types, some having a one piece tip with either a single orifice or a number of orifices, and others with two or more tips attached to one mixing head. The diameters of the tip orifices differ in order to control the quantity of heat and the type of flame. These tip sizes are designated by numbers which are arranged according to the individual manufacturer's system. In general, the smaller the number, the smaller the tip orifice.

b. A mixer (figure 5–10) is frequently provided in tip mixer assemblies to assure the correct flow of mixed gases for each size tip. In this tip mixer assembly the mixer is assembled with the tip for which it has been drilled and then screwed onto the torch head. The universal type mixer is a separate unit which can be used with tips of various sizes.

5.1.1.9 Hose.

a. The hose used to make the connection between the regulators and the torch is made especially for this purpose. It is built to withstand high internal pressures. It is strong, nonporous, light, and flexible to permit ready manipulation of the torch. The rubber used in its manufacture is chemically treated to remove free sulfur so as to avoid possible spontaneous combustion. The hose is not impaired by prolonged exposure to light.

b. The oxygen hose is green and the acetylene hose is red. The hose is a rubber tube with braided or wrapped cotton or rayon reinforcements and a rubber covering. For heavy duty welding and cutting operations, requiring 1/4 to 1/2 inch internal diameter hose, three to five plies of braided or wrapped reinforcements are used. One ply is used in the 1/8 to 3/16 inch hose for light torches.

c. Hoses are provided with connections at each end so that they may be connected to their respective regulator outlet and torch inlet connections. To prevent a dangerous interchange of acetylene and oxygen hoses all threaded fittings used for the acetylene hook up are left hand, and all threaded fittings for the oxygen hook up are right hand.

d. Welding and cutting hose is obtainable as a single hose for each gas or with the hoses bonded together along their length under a common outer rubber jacket. This type prevents the hose from kinking or becoming entangled during the welding operation.

5.1.1.10 Setting Up the Welding Equipment.

a. General. When setting up welding and cutting equipment it is important that all operations be performed systematically in order to avoid mistakes and possible trouble. The setting up procedures given in b through e below will assure safety to the operator and the apparatus.

b. Cylinders.

(1) Place the oxygen and the acetylene cylinders, if they are not mounted on a truck, on a level floor and tie them firmly to a work bench post, wall, or other secure anchorage to prevent their being knocked or pulled over.

WARNING

Do not stand facing cylinder valve outlets of oxygen, acetylene, or other compressed gases when opening them.

(2) Remove the valve protecting caps.

(3) "Crack" the cylinder valves by opening slightly for an instant to blow out any dirt or foreign matter that may have accumulated during shipment or storage.

(4) Close the valves and wipe off the connection seats with a clean cloth.

c. Pressure Regulators.

(1) Connect the acetylene regulator to the acetylene cylinder and the oxygen regulator to the oxygen cylinder. Use either a regulator wrench or a close fitting wrench and tighten the connecting nuts sufficiently to prevent leakage.

(2) Install safety check valves on oxygen/acetylene regulators before attaching individual hoses.

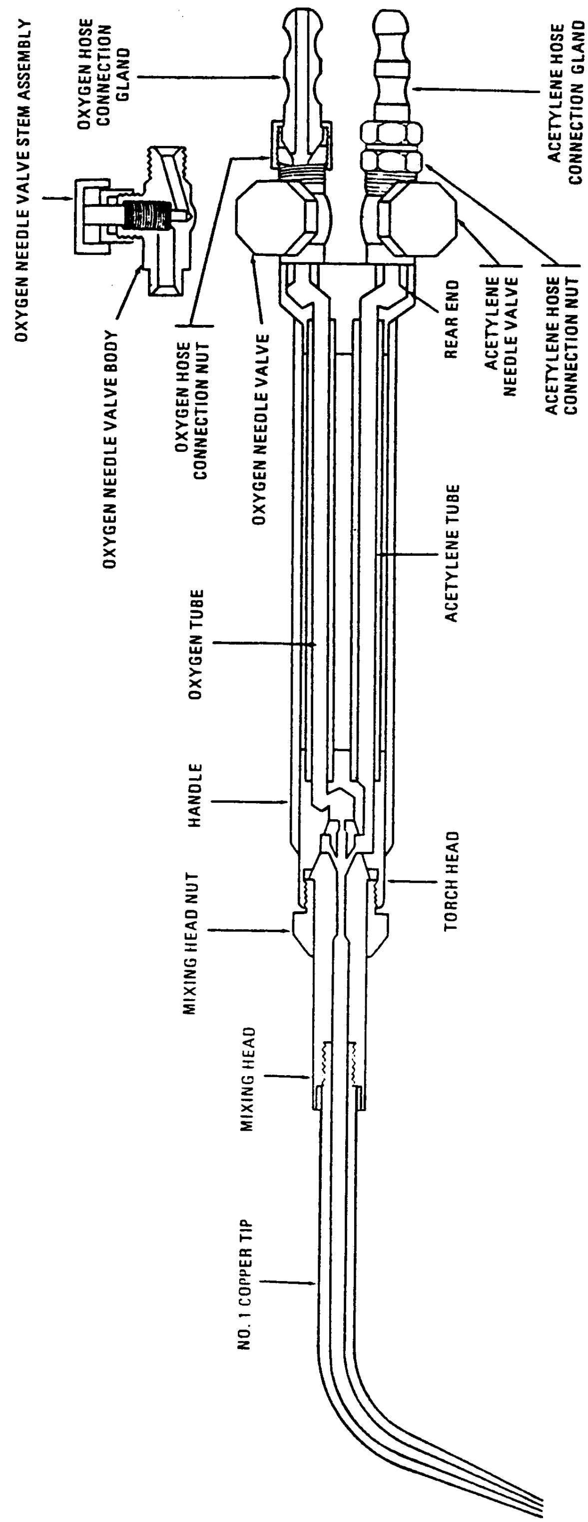


Figure 5–10. Equal Pressure Type, General Purpose Welding Torch

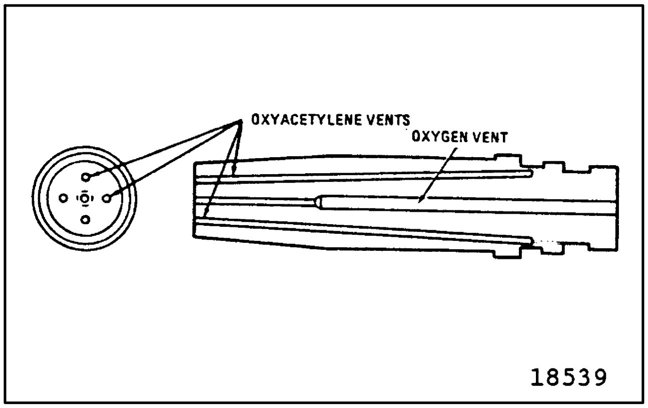


Figure 5–11. Diagram of Oxyacetylene Cutting Tip

(3) Connect the red hose to the acetylene regulator and the green hose to the oxygen regulator. Screw the connecting nuts up tightly to insure leak proof seating. Note that the acetylene hose connection has left hand threads.

WARNING

If it is necessary to blow out the acetylene hose, do it in a well ventilated place, free of sparks, flame, or other sources of ignition.

(4) Release the regulator screws to avoid damage to the regulators and gages.

WARNING

Do not stand directly in front or in back of the regulator when opening the cylinder valves. Stand off to one side.

(5) Slowly open the cylinder valves. Read the high pressure gages to check the cylinder gas pressure. Blow out the oxygen hose by turning the regulator screw in and then release the regulator screw.

d. Torch. Connect the red acetylene hose to the torch needle valve which is stamped AC. Connect the green oxygen hose to the torch needle valve which is stamped OX. Test all hose connections for leaks at the regulators or torch valves by turning both regulators screws in with the torch needle valves closed. Release the regulator screws after testing and drain both hose lines by opening the torch needle valves. Slip the tip nut over the mixing head, screw tip into mixing head and assemble in the torch body. Tighten by hand and adjust the tip to the proper angle. Secure this adjustment by tightening with the tip nut wrench.

WARNING

Purge both acetylene and oxygen lines (hoses) prior to igniting the torch. Failure to do this can cause serious injury to personnel and damage to the equipment.

e. Adjustment of Working Pressure. Adjust the acetylene working pressure by opening the acetylene needle valve in the torch and turning the regulator screw to the right, then adjust the acetylene regulator to the required pressure for the tip size to be used (see table 5–1). Close the needle valve.

f. Adjust the oxygen working pressure in the same manner.

5.1.1.11 Shutting Down Welding Apparatus.

a. Shut off the gases. First close the acetylene valve and then the oxygen valve on the torch. Then close the acetylene and oxygen cylinder valves.

b. Drain the regulators and hoses by the following procedures:

(1) Open the torch acetylene valve until the gas stops flowing, then close the valve.

(2) Next open the torch oxygen valve to drain the oxygen regulator and hose. When gas stops flowing, close the valve.

(3) When the above operations are performed properly both high and low pressure gages on the acetylene and oxygen regulators will register zero.

c. Release the tension on both regulator screws by turning the screws to the left until they rotate freely.

Table 5–1. Oxyacetylene Cutting Information

Plate Thickness (inch)	Cutting Tip[1] (size number)	Oxygen (psi)	Acetylene (psi)	Hand–cutting speed (inch per minute)
1/4	0	30	3	16 to 18
3/8	1	30	3	14.5 to 16.5
1/2	1	40	3	12 to 14.5
3/4	2	40	3	12 to 14.5
1	2	50	3	8.5 to 11.5
1 1/2	3	45	3	6.0 to 7.5
2	4	50	3	5.5 to 7.0
3	5	45	4	5.0 to 6.5
4	5	60	4	4.0 to 5.0
5	6	50	5	3.5 to 4.5
6	6	55	5	3.0 to 4.0
8	7	60	6	2.5 to 3.5
10	7	70	6	2.0 to 3.0
12	8	70	6	1.5 to 2.0

[1] Various manufacturers do not adhere to the numbering of tips as set forth in this table; therefore, some tips may carry different identification numbers.

d. Coil the hoses without kinking them and suspend them on a suitable holder or hanger. Avoid upsetting the cylinders to which they are attached.

5.1.1.12 Regulator Malfunctions and Corrections.

a. Leakage of gas between the regulator seat and the nozzle is the principal trouble encountered with regulators. It is indicated by a gradual increase in pressure on the working pressure gage when the adjusting screw is fully released or is in position after adjustment. This defect called "creeping regulator", is caused by bad valve seats or by foreign matter lodged between the seat and the nozzle.

WARNING

Regulators with leakage of gas between the regulator seat and the nozzle should be repaired immediately to avoid damage to other parts of the regulator or injury to personnel. With acetylene regulators this leakage is particularly dangerous because acetylene at high pressure in the hose is an explosion hazard.

b. The leakage of gas, as described above, can be corrected as outlined below:

(1) Remove and replace the seat if it is worn, cracked, or otherwise damaged.

(2) If the malfunction is caused by fouling with dirt or other foreign matter, clean the seat and nozzle thoroughly and blow out any dust or dirt in the valve chamber.

c. The procedure for removing valve seats and nozzles will vary with the make or design.

d. Broken or buckled gage tubes and distorted or buckled diaphragms are usually caused by backfire at the torch, leaks across the regulator seats, or by failure to release the regulator adjusting screw fully before opening the cylinder valves.

e. Defective bourdon tubes in the gages are indicated by improper action of the gages or by escaping gas from the gage case. Gages with defective bourdon tubes should be removed and replaced by new gages because satisfactory repairs cannot be made without special equipment.

f. Buckled or distorted diaphragms cannot be adjusted properly and should be replaced with new ones. Rubber diaphragms can be replaced easily by removing the spring case with a vise or wrench. Metal diaphragms are sometimes soldered to the valve case and their replacement is a factory or special repair shop job. It should not be attempted by anyone unfamiliar with the work.

5.1.1.13 Torch Malfunctions and Corrections.

a. General. Improper functioning of welding torches is usually due to one or more of the following causes: leaking valves, leaks in the mixing head seat, scored or out–of–round welding tip orifices, clogged tubes or tips, and damaged inlet connection threads. Corrective measures for these common torch defects are described below.

WARNING

Defects in oxyacetylene welding torches which are sources of gas leaks should be corrected immediately, as they may result in flashbacks or backfires, with resultant injury to the operator and/or damage to the welding apparatus.

b. Leaking Valves.

(1) This condition is due to worn or bent valve stems, damaged seats, or a combination of both. Loose packing will also cause leaks around the valve handle. Such leaks are indicated when the gases continue to flow after the valves are closed.

(2) Bent or worn valve stems should be replaced and damaged seats should be refaced.

(3) Loose packing may be corrected by tightening the packing nut or by installing new packing and then tightening the packing nut.

c. Leaks in the Mixing Heads. This condition is indicated by the popping out of the flame and by emission of sparks from the tips accompanied by a squealing noise. Leaks in the mixing head will cause improper mixing of the oxygen and acetylene which will cause flashbacks; i.e., ignition and burning of the gases back of the mixing head in the torch tubes. A flashback causes the torch head and handle to suddenly become very hot. This defect is corrected by reaming out and trueing the mixing head seat.

CAUTION

This work should be done by manufacturer because special reamers are required for trueing these seats.

d. Scored or Out–Of–Round Tip Orifices. Tips in this condition will cause the flame to be irregular even after the tip has been thoroughly cleaned. They cannot be repaired and must be replaced.

e. Clogged Tubes and Tips.

(1) This condition is due to carbon deposits caused by flashbacks or backfire, or to the presence of foreign matter that has entered the tubes through the hoses. If the tubes or tips are clogged, greater working pressures will be needed to produce the flame required for a given tip. The flame produced will be distorted.

(2) To correct this condition the torch should be disassembled so that the tip, mixing head, valves, and hose can be cleaned and blown out with compressed air at a pressure of 20 to 30 psi.

(3) The tip and mixing head should be cleaned either with a cleaning drill of the proper size or with soft copper or brass wire, and then blown out with compressed air. The cleaning drills should be approximately one drill size smaller than the tip orifice to avoid enlarging the orifice during cleaning.

f. Damaged Inlet Connection Threads. Leaks due to damaged inlet connection threads can be detected by opening the cylinder valves and keeping the needle valves closed. Such leaks will cause the regulator pressure to drop. Also, if the threads are damaged, the hose connection at the torch inlet will be difficult to impossible to tighten. To correct this defect the threads should be recut and the hose connections thoroughly cleaned.

WARNING

Damaged inlet connection threads may cause fires by ignition of the leaking gas, resulting in injury to the welding operator and/or damage to the equipment.

5.1.2 Oxyacetylene Cutting Equipment.

5.1.2.1 Oxyacetylene Cutting Torch and Other Cutting Equipment.

a. The cutting torch (figure 5–12) like the welding torch has a tube for oxygen and one for acetylene; in addition, there is a tube for high pressure oxygen, together with a cutting tip or nozzle. The tip (figure 5–13) is provided with a center hole through which a jet of pure oxygen passes. Mixed oxygen and acetylene pass through holes surrounding the center hole for the preheating flames. The number of orifices for oxyacetylene flames ranges from two to six, depending on the purpose for which the tip is used. The cutting oxygen is controlled by a trigger or lever operated valve. The cutting torch is furnished with interchangeable tips for cutting steel from less than 1/4 inch to more than 12 inches in thickness.

b. A cutting attachment fitted to a welding torch in place of the welding head is shown in figure 5–13.

5.1.2.2 Operation of Cutting Equipment.

a. Attach the required cutting tip to the torch and adjust the oxygen and acetylene pressures in accordance with table 5–1.

b. Adjust the preheating flame to neutral.

c. Hold the torch so that the cutting oxygen lever or trigger can be operated with one hand. Use the other hand to steady and maintain the position of the torch head to the work. Keep the flame at a 90 degree angle to the work in the direction of travel, with the inner cones of the preheating flames about 1/16 inch above the end of the line to be cut. Hold this position until the spot has been raised to a bright red heat and then slowly open the cutting oxygen valve.

d. If the cut has been started properly a shower of sparks will fall from the opposite side of the work. Then move the torch at a speed which will allow the cut to continue penetrating the work. A good cut will be clean and narrow.

e. When cutting billets, round bars, or heavy sections, time and gas are saved if a burr is raised with a chisel at the point where the cut is to start. This small portion will heat quickly and cutting will start immediately. A welding rod can also be used to start a cut on heavy sections. When so used, it is called a ”starting rod”.

5.1.3 Classification of Electrodes.

a. The American Welding Society’s classification number series has been adopted by the welding industry.

b. The electrode identification system for steel arc welding is set up as follows:

(1) E indicates electrode for arc welding.

(2) The first two (or three) digits indicate tensile strength (the resistance of the material to forces trying to pull it apart) in thousands of pounds per square inch, of the deposited metal.

(3) The third (or fourth) digit indicates the position of the weld. 1 is for all positions; 2 is for flat and horizontal positions only; 3 is for flat positions only.

(4) The fourth (or fifth) digit indicates the type of electrode coating and the type of power supply used; alternating or direct current, straight or reverse polarity.

(5) The types of coating, welding current, and polarity position designated by the fourth (or fifth) identifying digit of the electrode classification are as listed in table 5–2.

(6) The number E6010 indicates an arc welding electrode with a minimum stress relieved tensile strength of 60,000 psi. It can be used in all positions; and reverse polarity direct current is required.

c. The electrode identification system for stainless steel arc welding is set up as follows:

(1) E indicates electrode for arc welding.

(2) The first three digits indicate the American Iron and Steel Institute type of stainless steel.

(3) The last two digits indicate the current and position used.

(4) The number E–308–16 by this system indicates stainless steel type 308; with alternating or reverse polarity direct current; and it is used in all positions.

d. Bare Electrodes. Bare electrodes are made of wire compositions required for specific applications and have no coatings other than those required in wire drawing. These wire drawing coatings have some slight stabilizing effect on the arc but are otherwise of no consequence. Bare electrodes are used for welding manganese steel and other purposes where a coated electrode is not required or is undesirable. A diagrammatical sketch of the transfer of metal across the arc of a bare electrode is shown in figure 5–14.

Table 5–2. Coating, Current and Politarity Types as Designated by the Fourth Digit in the Electrode Classification Number

Digit	Coating	Weld Current
0	Cellulose sodium	dcrp
1	Cellulose potassium	ac, dcrp, dcsp
2	Titania sodium	ac, dcsp
3	Titania potassium	ac, dcsp, dcrp
4	Iron powder titania	ac, dcsp, dcrp
5	Low hydrogen sodium	dcrp
6	Low hydrogen potassium	ac, dcrp
7	Iron powder iron oxide	ac, dcsp
8	Iron powder low hydrogen	ac, dcrp, dcsp

e. Light Coated Electrodes.

(1) Light coated electrodes have a definite composition. A light coating has been applied on the surface by washing, dipping, brushing, spraying, tumbling, or wiping to improve the stability and characteristics of the arc stream.

(2) The coating generally serves the functions described below:

(a) It dissolves or reduces impurities such as oxides, sulfur, and phosphorus.

(b) It changes the surface tension of the molten metal so that the globules of metal leaving the end of the electrode are smaller and more frequent, making the flow of molten metal more uniform.

(c) It increases the arc stability by introducing materials readily ionized (i.e., changed into small particles with an electric charge) into the arc stream.

(3) Some of the light coatings may produce a slag, but it is quite thin and does not act in the same manner as the shielded arc electrode type slag. The arc action obtained with light coated electrodes is shown in figure 5–15.

f. Storing Electrodes. Electrodes must be kept dry. Moisture destroys the desirable characteristics of the coating and may cause excessive spattering and lead to the formation of cracks in the welded area. Electrodes exposed to damp air for more than two or three hours should be dried by heating in a suitable oven (figure 5–16) for two hours at 500− F (260− C). After they have been dried, they should be stored in a suitable container.

g. Shielded Arc or Heavy Coated Electrodes. Shielded arc or heavy coated electrodes have a definite composition on which a coating has been applied by dipping, extrusion, or other suitable process. The electrodes are manufactured in three general types: those with cellulose coatings; those with mineral coatings; and those whose coatings are combinations of mineral and cellulose. The cellulose coatings are composed of soluble cotton or other forms of cellulose with small amounts of potassium, sodium, or titanium, and in some cases added minerals. The mineral coatings consist of sodium silicate, metallic oxides, clay, and other inorganic substances or combinations thereof. Cellulose coated electrodes protect the molten metal with a gaseous zone around the arc as well as slag deposit over the weld. The mineral coated electrode forms a slag deposit only. The shielded arc or heavy coated electrodes are used for welding steels and cast iron, hard surfacing, and other purposes. The arc action obtained with the shielded arc or heavy coated electrode is shown in figure 5–17.

h. Functions of Shielded Arc or Heavy Coated Electrodes.

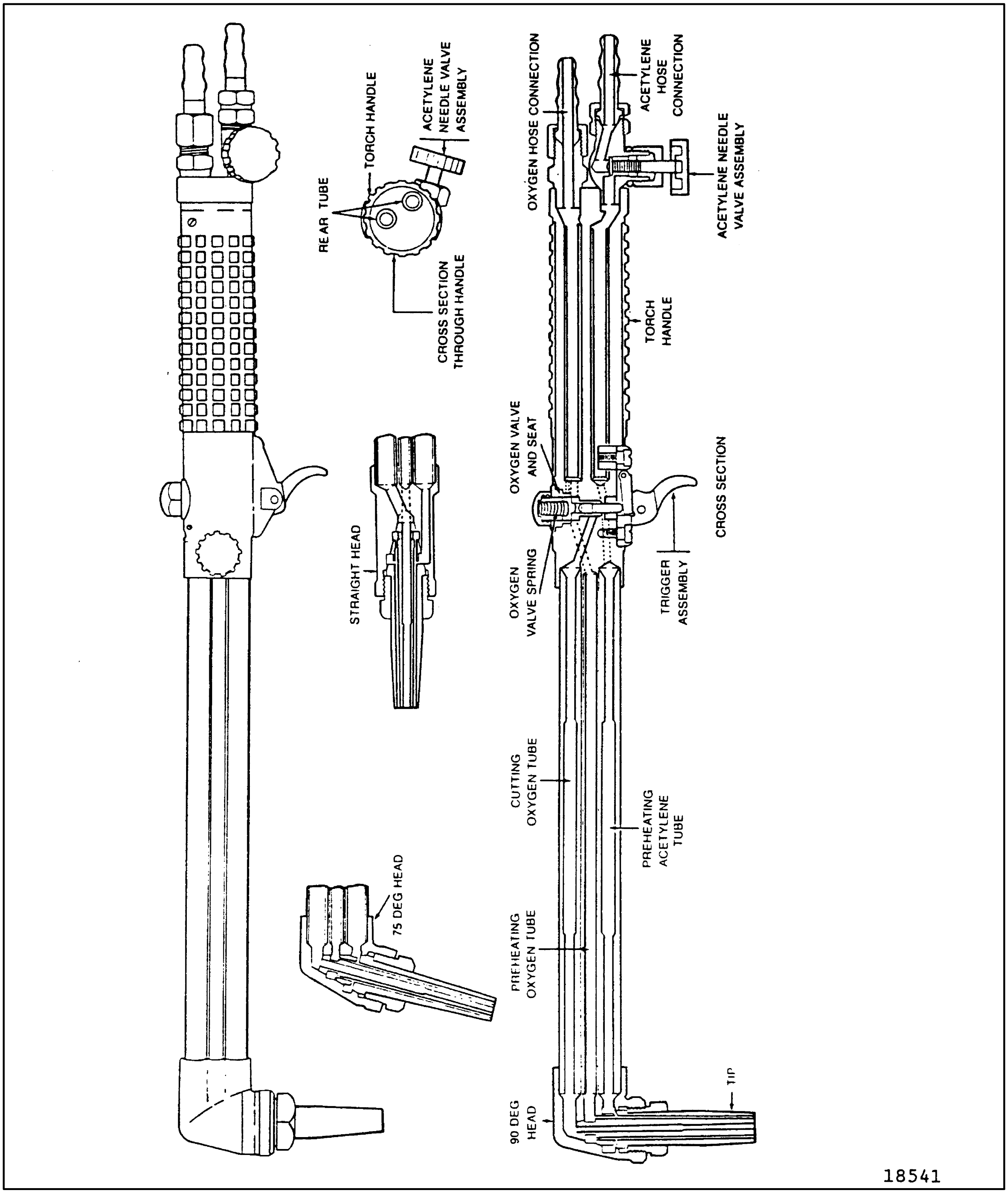


Figure 5–12. Oxyacetylene Cutting Torch

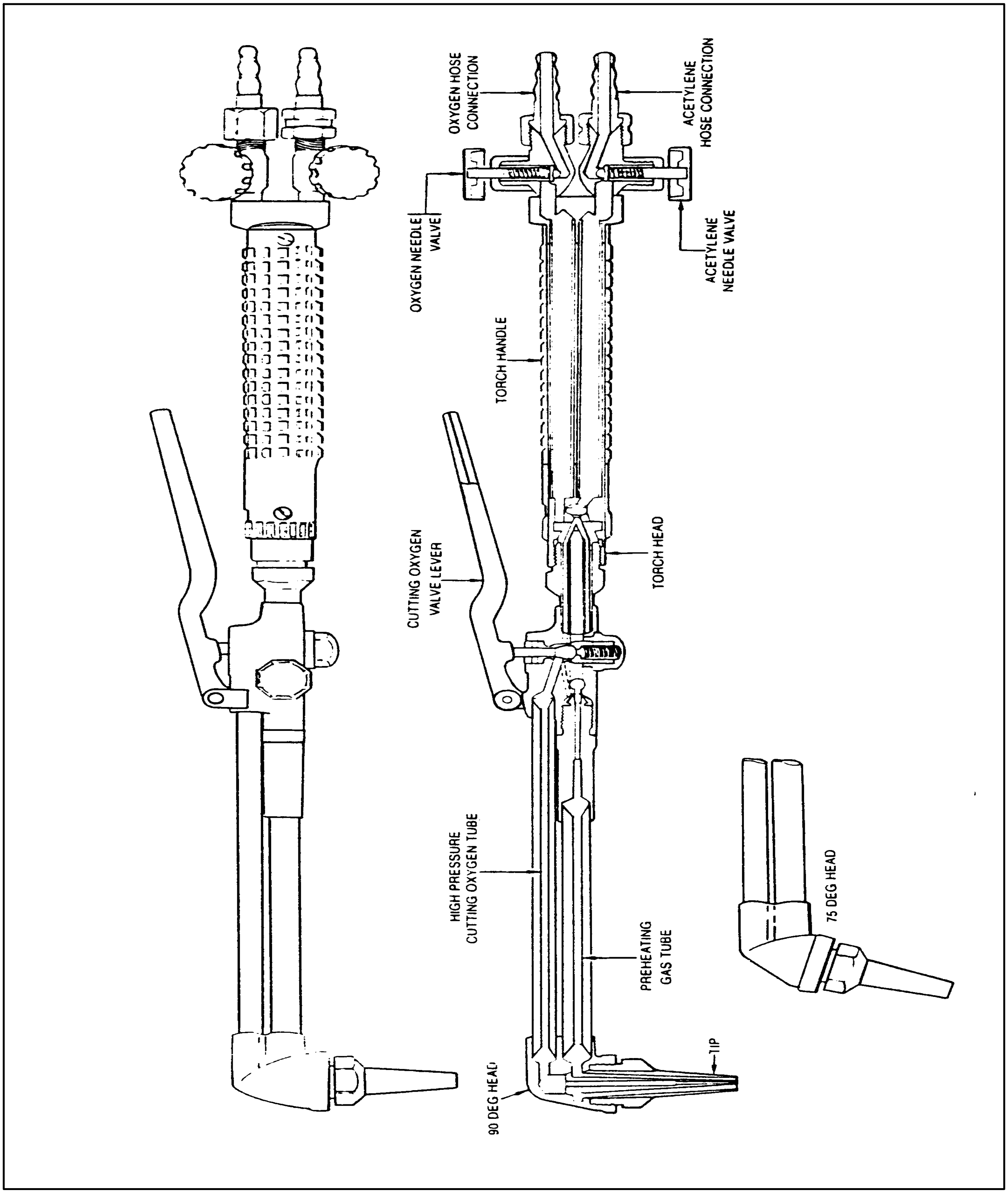


Figure 5–13. Cutting Attachment for Welding Torch

(1) These electrodes produce a reducing gas shield around the arc which prevents atmospheric oxygen or nitrogen from contaminating the weld metal. The oxygen would readily combine with the molten metal, removing alloying elements and causing porosity. The nitrogen would cause brittleness, low ductility, and in some cases low strength and poor resistance to corrosion.

(2) They reduce impurities such as oxides, sulfur, and phosphorus so that these impurities will not impair the weld deposit.

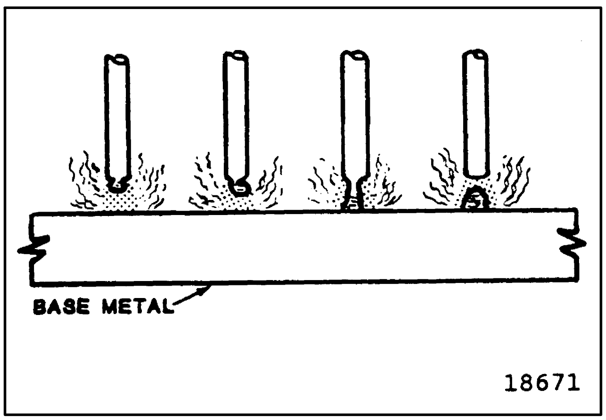


Figure 5-14. Molten Metal transfer with a Bare Electrode

(3) They provide substances to the arc which increase its stability and eliminate wide fluctuations in the voltage so that the arc can be maintained without excessive spattering.

(4) By reducing the attractive force between the molten metal and the end of the electrode, or by reducing the surface tension of the molten metal, the vaporized and melted coating causes the molten metal at the end of the electrode to break up into fine, small particles.

(5) The coatings contain silicates which will form a slag over the molten weld and base metal. Since the slag solidifies at a relatively slow rate it holds the heat and allows the underlying metal to cool and solidify slowly. This slow solidification of the metal eliminates the entrapment of gases within the weld and permits solid impurities to float to the surface. Slow cooling also has an annealing effect on the weld deposit.

(6) The physical characteristics of the weld deposit are modified by incorporating alloying materials in the electrode coating. Also the fluxing action of the slag will produce weld metal of better quality and permit welding at higher speeds.

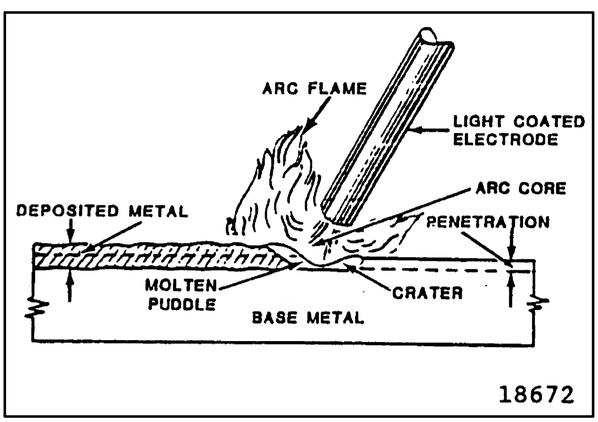


Figure 5-15. Arc Action Obtained with a Light Coated Electode

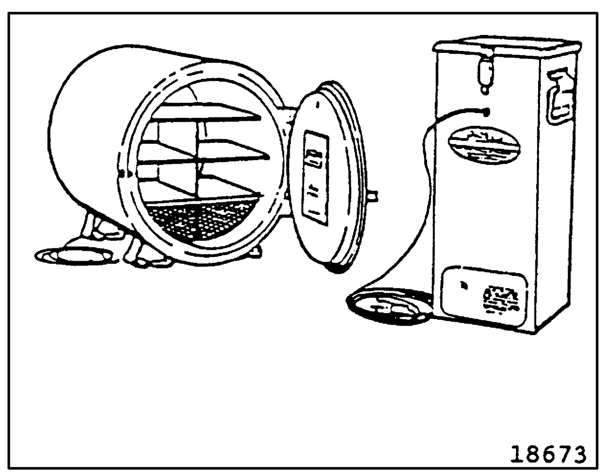


Figure 5-16. Electrode Drying Ovens

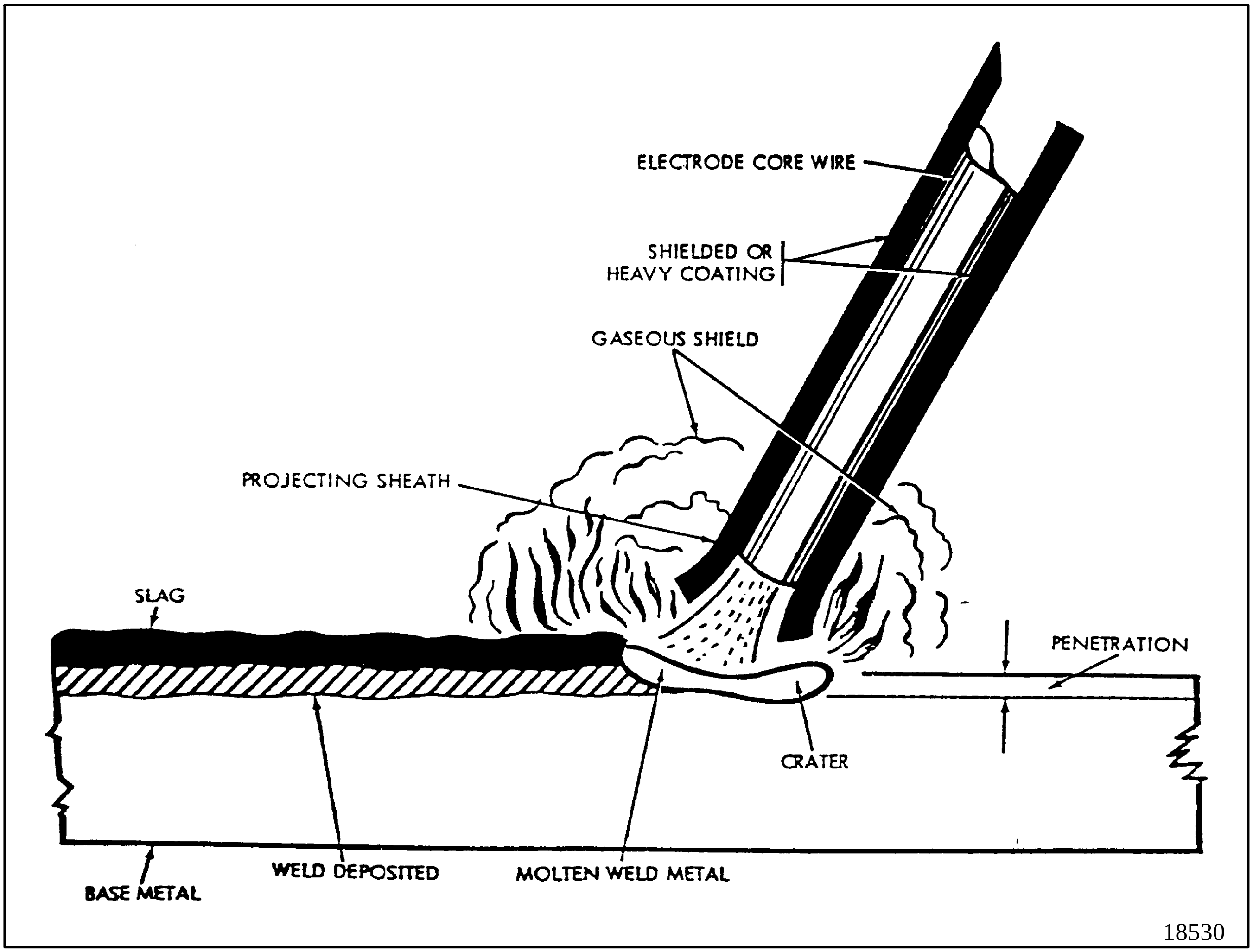


Figure 5–17. Arc Action Obtained with a Shielded Arc Electrode

(7) The coating insulates the sides of the electrode so that the arc is concentrated into a confined area. This facilitates welding in a deep U or V groove.

(8) The coating produces a cup, cone, or sheath (figure 5–17) at the tip of the electrode which acts as a shield, concentrates and directs the arc, reduces heat losses and increases the temperature at the end of the electrode.

i. Direct Current Arc Welding Electrodes.

(1) The manufacturer's recommendations should be followed when a specific type of electrode is being used. In general, direct current shielded arc electrodes are designed either for reverse polarity (electrode positive) or for straight polarity (electrode negative) and are interchangeable. Many, but not all of the direct current electrodes can be used with alternating current. Direct current is preferred for many types of covered nonferrous, bare and alloy steel electrodes. Recommendations from the manufacturer also include the type of base metal for which given electrodes are suitable, corrections for poor fit–ups, and other specific conditions.

(2) In most cases reverse polarity electrodes will provide less penetration than straight polarity electrodes, and for this reason will permit greater welding speed. Good penetration can be obtained from either type with proper welding conditions and arc manipulations.

j. Alternating Current Arc Welding Electrodes.

(1) Coated electrodes which can be used with either direct or alternating current are available. Alternating current is more desirable while welding in a restricted area or when using the high currents required for thick sections because it reduces arc blow. Arc blow causes blowholes, slag inclusions, and lack of fusion in the weld.

(2) Alternating current is used in atomic hydrogen welding and in those carbon–arc processes that require the use of two carbon electrodes. It permits a uniform rate of welding and electrode consumption. In carbon–arc processes where one carbon electrode is used, direct current straight polarity is recommended, because the electrode will be consumed at a lower rate.

k. Electrode Defects and Their Effect.

(1) If certain elements or their oxides are present in electrode coatings the arc stability will be affected. In bare electrodes the composition and uniformity of the wire is an important factor in the control of arc stability. Thin or heavy coatings on electrodes will not completely remove the effects of defective wire.

(2) Aluminum or aluminum oxide (even when present in quantities not exceeding 0.01 percent), silicon, silicon dioxide, and iron sulfate cause the arc to be unstable. Iron oxide, manganese oxide, calcium oxide, and iron sulfide tend to stabilize the arc.

(3) When phosphorus or sulfur are present in the electrode in excess of 0.04 percent they will impair the weld metal because they are transferred from the electrode to the molten metal with very little loss. Phosphorus causes grain growth, brittleness, and "cold shortness" (i.e., brittle when below red heat) in the weld, and these defects increase in magnitude as the carbon content of the steel increases. Sulfur acts as a slag, breaks up the soundness of the weld metal, and causes "hot shortness" (i.e., brittle when above red heat). Sulfur is particularly harmful to bare low carbon steel electrodes with a low manganese content. Manganese promotes the formation of sound welds.

(4) If the heat treatment given the wire core of an electrode is not uniform the electrode will produce welds inferior to those produced with an electrode of the same composition that has been properly heat treated.

5.1.4 Arc Welding Equipment and Accessories.

5.1.4.1 General. The electrical equipment required for arc welding depends on the source from which the electric power is obtained. If the power is obtained from utility lines one or more of the following devices is required: transformers (of which there are several types), rectifiers, motor generators, and control equipment. If public utility power is not available, portable generators driven by gasoline or diesel engines are used.

5.1.4.2 Direct Current Welding Machines.

a. The direct current welding machine has a heavy duty direct current generator. The generators are made in six standardized ratings for general purposes as described below:

(1) The machines rated 150 and 200 amperes, 30 volts, are used for light shielded metal–arc welding and for gas metal–arc welding. They are also used for general purpose job shop work.

(2) The machines rated 200, 300, and 400 amperes, 40 volts, are used for general welding purposes by machine or manual application.

(3) Machines rated 600 amperes, 40 volts, are used for submerged arc welding and for carbon–arc welding.

b. The electric motors most commonly used to drive the welding generators are 220/440 volts, 3 phase, 60 cycle. The gasoline and diesel engines should have a rated horsepower in excess of the rated output of the generator. This will allow for the rated overload capacity of the generator and for the power required to operate the accessories of the engine. The simple equation

$$HP = \frac{1.25 \text{ X } P}{746} \quad \text{can be used;}$$

HP is the engine horsepower and P is the generator rating in watts. For example, a 20 horsepower engine would be used to drive a welding generator with a rated 12 kilowatt output.

c. In most direct current welding machines the generator is of the variable voltage type, and is so arranged that the voltage is automatically adjusted to the demands of the arc. However, the voltage may be set manually with a rheostat.

d. The welding current amperage is also manually adjustable and is set by means of a selector switch or series of plug receptacles. In either case the desired amperage is obtained by tapping into the generator field coils. When both voltage and amperage of the welding machine are adjustable the machine is known as a dual control type. Welding machines are also manufactured in which current controls are maintained by movement of the brush assembly.

e. A maintenance schedule should be set up to keep the welding machine in good operating condition. The machine should be thoroughly inspected every 3 months and blown free of dust with clean, dry, compressed air. At least once each year the contacts of the motor starter switches and the rheostat should be cleaned and replaced if necessary. Brushes should be inspected frequently to see if they are making proper contact on the commutator, and that they move freely in the brush holders. Clean and true the commutator with sandpaper or a commutator stone if it is burned or roughened. Check the bearings twice a year. Remove all the old grease and replace it with new grease.

f. Direct current rectifier type welding machines have been designed with copper oxide, silicon, or selenium dry plates. These machines usually consist of a transformer to reduce the power line voltage to the required 220/440 volts, 3 phase, 60 cycle input current; and a rectifier to change the alternating current to direct current. Sometimes another reactor is used to reduce ripple in the output current.

5.1.4.3 Alternating Current Arc Welding Machines.

a. Practically all of the alternating current arc welding machines in use are of the single operator, static transformer type. For manual operation in industrial applications, machines having 200, 300, and 400 ampere ratings are the sizes in general use. Machines with 150 ampere ratings are sometimes used in light industrial, garage and job shop welding.

b. The transformers are generally equipped with arc stabilizing capacitors. Current control is provided in several ways. One such method is by means of an adjustable reactor in the output circuit of the transformer; in other types the internal reactions of the transformer are adjustable. A handwheel, usually installed on the front or the top of the machine, makes possible continuous adjustment of the output current without steps.

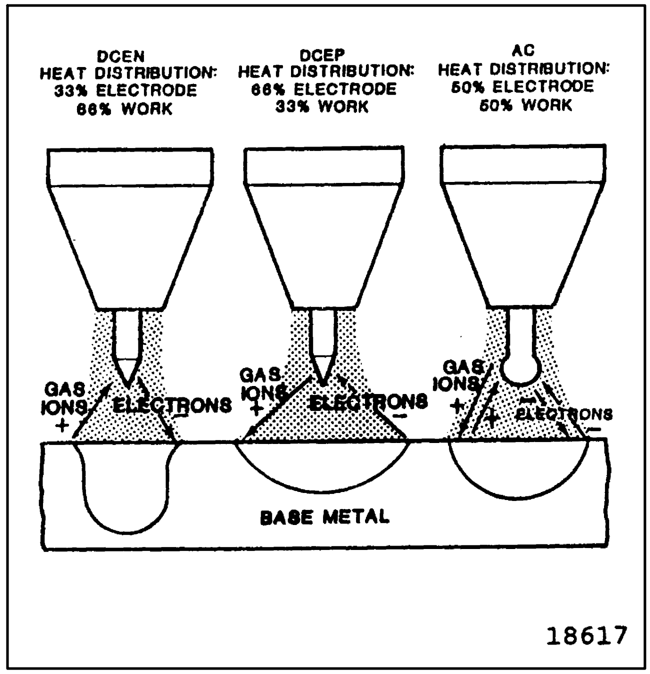


Figure 5–18. Heat Distribution

c. The screws and bearings on machines with screw type adjustments should be lubricated every 3 months. The same lubrication schedule will apply to chain drives. Contactors, switches, relays, and plug and jack connections should be inspected every 3 months and cleaned or replaced as required. The primary input current at no load should be measured and checked once a year to make certain that the power factor connecting capacitors are working, and that input current is as specified on the nameplate or in the manufacturer's instruction book.

5.1.4.4 Gas Tungsten–Arc (GTAW) Welding Equipment.

a. GAS TUNGSTEN ARC WELDING (GTAW) is a process used to produce high quality welds in virtually all weldable metals. It is done manually or automatically. Gas tungsten arc welding (GTAW) is also known as TIG (tungsten inert gas) welding. It was originally called Heliarc welding when it was first developed.

b. Welding is done normally with one tungsten electrode, but multiple electrodes have been used in special applications. Gas tungsten arc welding may be done in any welding position. It is used to weld thin walled pipe and tube. The process is also used almost exclusively to weld the root bead in heavy walled pipe in petroleum, chemical, and power generating applications. Filler metal may or may not be required with

GTAW. Flange joints on thin metal may be designed for welding without filler metal.

c. Inert gases are used to shield the GTAW from atmospheric contamination.

d. The welder must manipulate the gas tungsten arc welding torch to control the arc length. The welder must also carefully add the filler metal when doing manual GTAW. Manual gas tungsten arc welding therefore requires more welder skill than gas metal arc welding.

5.1.5 <u>Gas Tungsten Arc Welding Principles</u>.

a. Gas tungsten arc welding requires the use of a torch, an inert gas, gas regulating equipment, a constant current power supply, and filler metal when required.

b. Direct current (DC) or alternating current (AC) power supplies may be used. Either direct current electrode negative (DCEN) (DCSP) or direct current electrode positive (DCEP) (DCRP) may be used. When doing GTAW with DCEN, two thirds of the heat generated in the arc is released on the work piece and one third is released at the electrode. In DCEP, two thirds of the heat generated is released at the electrode and one third on the work. When DCEP is used for GTAW, a larger diameter electrode must be used than when DCEN is used. Figure 5–18 shows how the electrons flow and how the heat is distributed when DCEN, DCEP, or AC is used with GTAW. The current carrying capacity of an electrode using DCEP is only about one tenth that of an electrode using DCEN. DCEN is therefore used most often.

c. Filler metal is added to the arc pool either manually or automatically. When doing manual GTAW, the filler metal is added in much the same way as when doing oxyfuel gas welding. A flange may be bent up on thin metal and used as the filler metal.

d. Using automatic GTAW, metal as thin as .003 in. (.076 mm) may be welded using a flanged joint.

e. The filler metal used for automatic GTAW is usually in the form of spooled wire. The wire is fed into the arc pool as shown in figure 5–19. Thicknesses above .02 in. (.51 mm) are generally joined using an added filler metal.

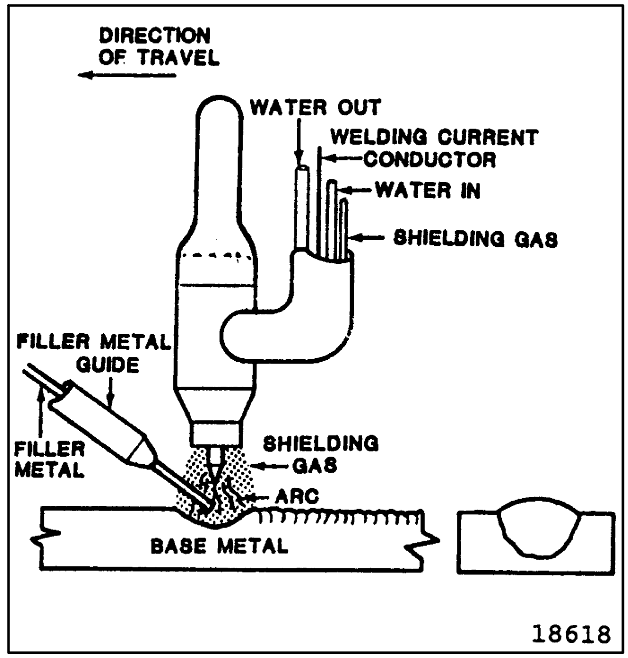


Figure 5–19. Automatic GTAW

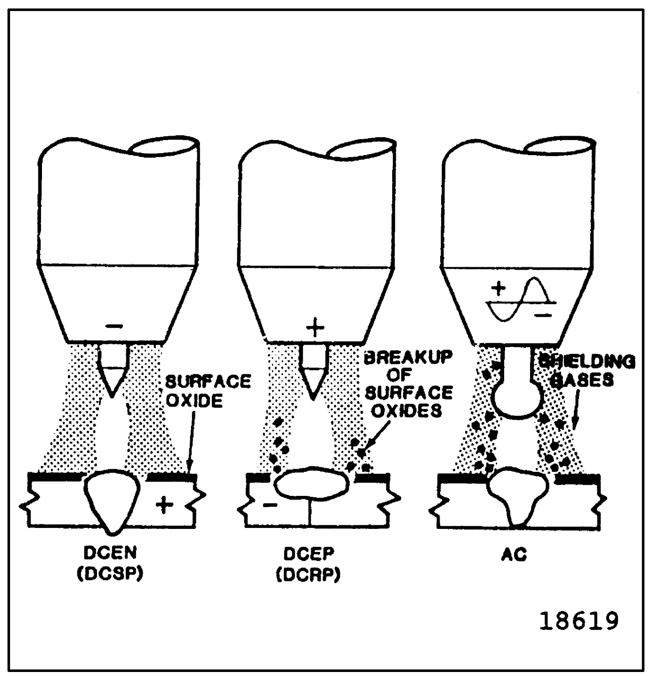


Figure 5–20. Examples of Current

f. Alternating current or direct current electrode positive (DCEP) or DCRP is used when surface oxides must be removed. Surface oxides occur on aluminum, magnesium, and some other nonferrous metals. These metal oxides melt at a higher temperature than the base metal. The oxides therefore make it hard to weld the base metal.

g. Electrons flow from the work to the electrode when DCEP is used and during one half of the AC cycle. However, positively charged shielding gas ions travel from the nozzle to the negatively charged work; see figure 5–18. These shielding gas ions strike the work surface with sufficient force to break up the oxides. DCEP and AC both work well in breaking up the surface oxides on aluminum and magnesium. See figure 5–20. AC gives better penetration. AC can also be used with a smaller electrode diameter for a given current flow.

5.2 GTAW POWER SOURCES.

a. Direct current electrode negative (DCEN) (DCSP) is used when the greatest amount of heat is to be on the base metal. DCEN is also used when welding thicker sections and for deepest penetration. See figure 5–18. Direct current electrode positive (DCEP) (DCRP) is used to weld thin metal sections. DCEP or AC is used for the best surface cleaning action when welding aluminum or magnesium. An alternating current source is chosen when equal heating is preferred. AC is also used for medium penetration welds.

b. The power source may be able to furnish steady or pulsing current. Pulsing current is the best choice when welding out of position.

c. During half of the alternating current (AC) cycle, the electrode is positive. Electrons do not travel easily from the flat work surface to the relatively small tungsten electrode tip. This may cause a blocking (rectification) or unbalancing of the current flow during the electrode positive half of the AC cycle. See A, figure 5–21. Rectification can be avoided or reduced by increasing the open circuit voltage of the welding machine. See B, figure 5–21. The alternating current wave form is said to be stabilized when some current flows during the electrode positive half of the cycle. It may also be stabilized by adding a high frequency voltage circuit in series with the welding circuit. This added high frequency circuit provides several thousand volts with an extremely low current or amperage. A high frequency volt age is continually applied in the AC welding circuit for GTAW.

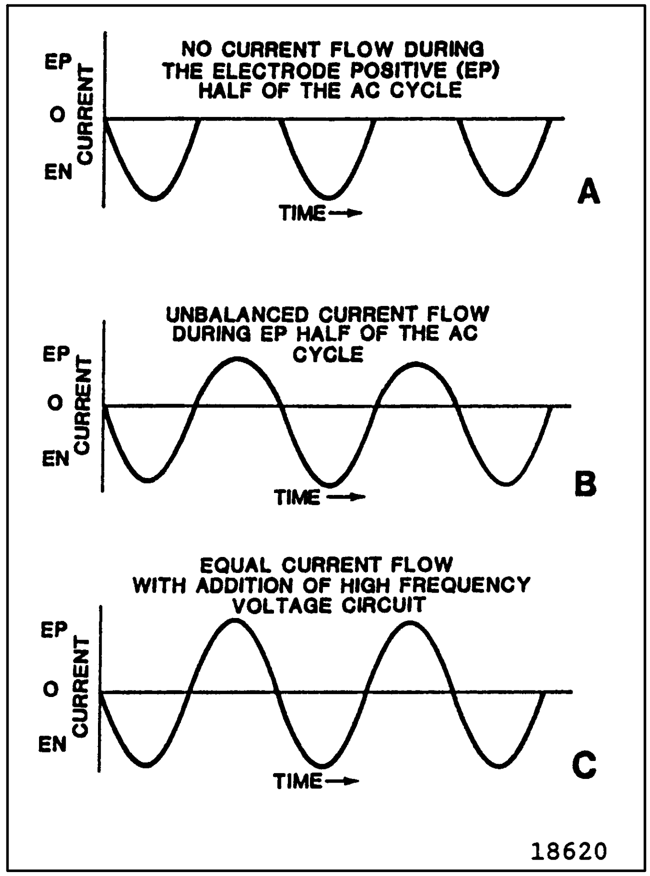


Figure 5–21. Alternating Current Wave Forms

d. High frequency or a higher open circuit voltage will stabilize the AC wave form, but the wave form is still unbalanced. To balance the AC wave form, capacitors are used to increase the current flow during the EP half cycle. Capacitors store electricity during the EN half cycle and release the electricity during the EP half cycle. Through the use of capacitors, a balanced AC wave form is obtained. See C, figure 5–21.

e. Gas tungsten arc welding is always done with a power source which furnishes a CONSTANT CURRENT supply. The current setting will be determined by the size of the electrode, metal thickness, shielding gas used, and the type of current supplied.

5.3 THE GAS TUNGSTEN ARC WELDING STATION.

a. The typical gas tungsten arc welding (GTAW) outfit will contain the following equipment and supplies:

(1) An AC or DC arc welding machine.

(2) Shielding gas cylinders or facilities to handle liquid gases.

(3) A shielding gas regulator.

(4) A gas flowmeter.

(5) Shielding gas hoses and fittings.

(6) Electrode lead and hoses.

(7) A welding torch (electrode holder).

(8) Tungsten electrodes.

(9) Welding rods.

(10) Optional accessories.

(a) A water cooling system with hoses for heavy duty welding operations.

(b) Foot rheostat.

(c) Arc timers.

b. Figure 5–22 shows a schematic drawing of a gas tungsten arc welding outfit. The booth and exhaust system are not shown in this illustration.

c. The arc welding machine (not shown but adequately described) should be given a brief safety inspection prior to its use. With the main power switch off, check the ground and electrode lead connections for a tight connection on the machine. Check the entire length of each lead for evidence of wear or cuts. These could indicate internal damage to the conducting cables. Keep the leads protected with a steel channel whenever they must run across an aisleway. The ground lead clamp or connection should be checked for a good connection. The contact area of the ground clamp or connection must be clean for the best current flow conditions. All shielding gas connections must be tight. This will prevent expensive gas leaks. Loose connections may also allow air to enter the shielding gas lines. This will cause contamination of the electrode and the weld.

d. A remote control foot switch performs many functions. When the pedal is pressed, the shielding gas and cooling water begin to flow. The switch is used to control the welding current. As the pedal is pressed, more current is supplied to the torch. The pedal can also be used as a current on–off switch without varying the current. If a remote control foot switch is used, the plug must be firmly installed in the arc welder receptacle. A microswitch on the torch handle may also be used to perform these functions.

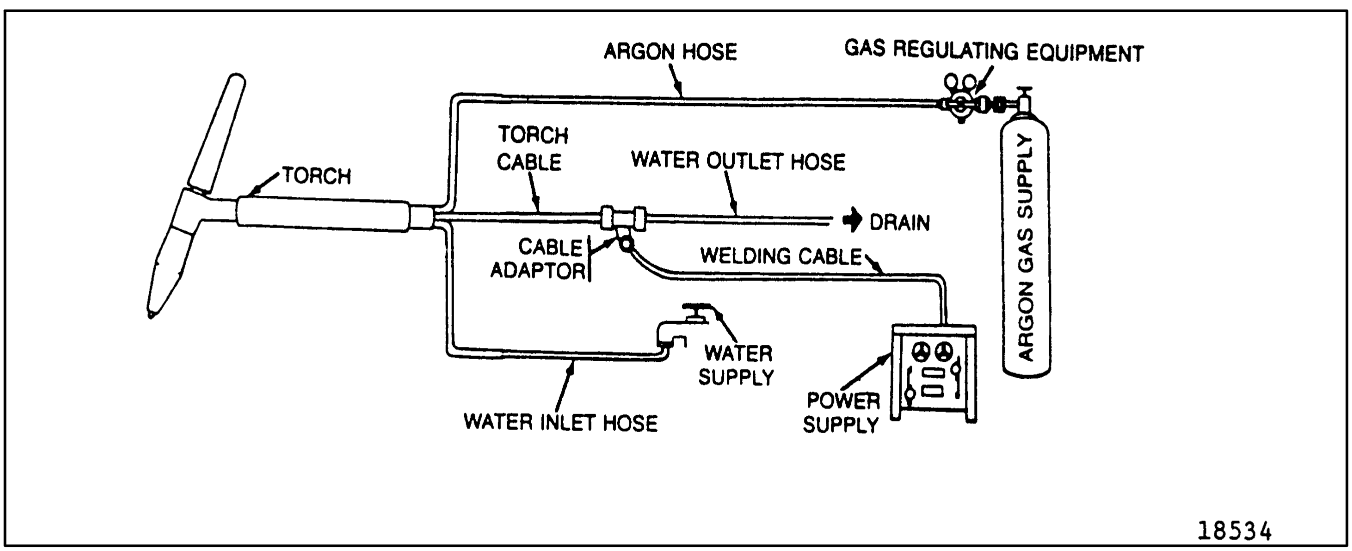


Figure 5–22. Gas Tungsten–Arc Welding Setup

e. The control panel contains the following controls which are explained below:

(1) The RANGE SELECTOR is used to select a high or low current range.

(2) The CURRENT CONTROL DIAL CONTROL KNOB is used to set the desired current. This dial is marked in white for the high range settings. It is marked in black for the low range settings.

(3) Alternating or direct current may be selected by the setting of the AC/DC SELECTOR SWITCH.

(4) Direct current electrode negative (DCEN) (DCSP) or direct current electrode positive (DCEP) (DCRP) may be selected by the setting of the POLARITY SWITCH.

(5) The POWER SWITCH is used to turn the arc welding machine primary circuit on or off. The machine should not be turned off while the arc is struck. The machine should only be turned on or off while the GTAW torch is hung on an insulated hook

(6) The POST–FLOW TIMER or after flow timer is used to control how long in seconds the shielding gas will flow after the arc is stopped. The gas should flow for 10–15 seconds to keep the hot electrode from becoming contaminated. A good rule to use is to continue the gas flow one second for each 10 amperes of current used.

(7) The VOLTMETER will show open circuit voltage and it will show the closed circuit voltage while welding.

(8) (The AMMETER will indicate the current flow while welding.

(9) The CONTACTOR SWITCH has two positions, standard and remote. In the standard position, a switch on the control panel is used to turn the machine's secondary circuit on or off. The standard position is generally used for SMAW. In this position the electrode has open circuit voltage to it. When the switch is in the remote position, a thumb switch on the torch or a remote foot switch is used to turn the secondary welding circuit on or off. In the remote position the secondary current, and the water, and gas flow are started when the thumb switch or foot switch is depressed slightly.

(10) The REMOTE OR CONTROL PANEL CURRENT SWITCH has two positions. In the remote position, the current may be varied at the welding site. In the panel position, the current is changed on the machine panel only.

(11) The HIGH FREQUENCY SWITCH has two positions. In the start position, high frequency is applied to the welding circuit only until the arc is struck. This position is used when DC is used. In the continuous position, high frequency is applied to the welding circuit constantly. This position is used when AC is used for GTAW.

(12) The START CURRENT SWITCH AND CONTROL work together. The control is marked from 0 – 10. This control will set a starting current from low (1) to high (10). After the arc is stabilized, the regular weld(ing current will automatically come into use.

5.4 SELECTING PROPER SHIELDING FOR GTAW.

a. High quality welds using the gas tungsten arc can only be made using either argon (Ar), helium (He), or argon–helium mixtures. Both argon and helium are inert gases. Table 5–3 describes usage of shielding gases and power sources for different base metals.

b. Argon (Ar) provides a smoother, quieter arc. A lower arc voltage is required and it provides a better cleaning action than helium. Argon is ten (10) times heavier than helium. Argon provides better shielding than helium with less gas.

c. Helium (He) however, provides a higher available heat at the workpiece than does argon. GTAW done with helium gas produces deeper penetration than does argon gas.

d. Both argon and helium produce good welds with direct current. Helium is best for use on thicker metal sections than argon because of its higher available heat.

e. Alternating current GTAW cannot be done acceptably with helium gas. AC with argon is suggested only for use on aluminum and its alloys. Argon and helium gas mixtures are used in some applications. These mixtures contain up to 75 percent helium. They produce a weld with deeper penetration and they have a good cleaning action.

Table 5–3. Suggested Choices of Shielding Gases and Power Sources for Welding Various Metals

METAL	THICKNESS	MANUAL	AUTOMATIC (MACHINE)
Aluminum and aluminum alloys	Under 1/8 in. (3.2 mm) Over 1/8 in. (3.2 mm)	Ar[1] (AC–HF) Ar (AC–HF)[3]	Ar (AC–HF) or He[2] (DCEN) Ar–He (AC–HF) or He (DCEN)[4]
Copper	Under 1/8 in. (3.2 mm) Over 1/8 in. (3.2 mm)	Ar–He (DCEN) He (DCEN)	Ar–He (DCEN) He (DCEN)
Nickel alloys	Under 1/8 in. (3.2 mm) Over 1/8 in. (3.2 mm)	Ar (DCEN) Ar–He (DCEN)	Ar–He (DCEN) or He (DCEN) He (DCEN)
Steel, carbon	Under 1/8 in. (3.2 mm) Over 1/8 in. (3.2 mm)	Ar (DCEN) Ar (DCEN)	Ar (DCEN) Ar (DCEN) or Ar–He (DCEN)
Steel, stainless	Under 1/8 in. (3.2 mm) Over 1/8 in. (3.2 mm)	Ar (DCEN) Ar–He (DCEN)	Ar–He (DCEN) or H_2[5] (DCEN) He (DCEN)
Titanium and its alloys	Under 1/8 in. (3.2 mm) Over 1/8 in. (3.2 mm)	Ar (DCEN) Ar–He (DCEN)	Ar (DCEN) or Ar–He (DCEN) He (DCEN)

l – Ar (argon)
2 – He (helium)
3 – AC–HF (alternating current, high frequency)
4 – DCEN (direct current electrode negative, also DCSP)
5 – H_2 (hydrogen)

f. Hydrogen (H_2) is added to argon when welding stainless steel, nickel–copper, and nickel based alloys. The addition of hydrogen to argon permits increased welding speeds. Hydrogen is not recommended for use on other metals because it produces hydrogen cracks in the welds. The argon–hydrogen gas mixture contains up to 15 percent hydrogen.

5.5 SELECTING CORRECT SHIELDING GAS FLOW RATE FOR GTAW.

a. The FLOW RATE is the volume of gas flowing. The rate of flow is measured in cubic feet per hour or liters per minute. This flow rate varies with the base metal being welded, the thickness of the base metal, and the position of the welded joint. A higher gas flow rate is required when welding overhead. This is because that argon being heavier than air tends to fall away from the overhead joint.

b. Table 5–4 lists suggested flow rates for GTAW welding various base metals, thickness and welding positions.

c. After determining the correct gas and flow rate, the flow rate must be properly set on the flowmeter. The vertical tube gas flowmeter is most common. See figure 5–23 for a schematic of a gas flowmeter.

d. Before setting the flowmeter, the shielding gas cylinder must be opened. The procedure for opening the shielding gas cylinder is as follows:

(1) Turn the regulator adjusting screw outward in a counter clockwise direction. This insures that the regulator is closed. Note: When a preset pressure is set on the regulator, no adjusting handle is used. Once the pressure is set, an acorn nut is placed over the adjusting screw. In this case, the regulator is always open.

(2) Open the cylinder valve SLOWLY. Continue to open it until it is fully opened. This is necessary because a back seating valve is used to seal the valve stem from leakage.

(3) If a regulator adjusting screw is used, turn it in to the pressure at which the flowmeter is calibrated. Most flowmeters are calibrated at 50 psig (344.7 kPa). The calibrating pressure should be indicated somewhere on the flowmeter.

Table 5–4. Suggested Shielding Gas Flow Rates for GTAW Various Metals, Thicknesses, and Positions

Base Metal	Joint	Thick–ness	Weld* Position	Flow (CFH)		Flow (L/Min) Argon	Flow (L/Min) Helium
				Argon	Helium		
Aluminum and Aluminum Alloys	Fillet, lap, edge, and corner	1/16	FVH	16		7.55	
			0	20		9.44	
		3/32	FVH	18		8.50	
			0	20		9.44	
	Butt	1/16, 3/32, 1/8	FVH	20		9.44	
			0	25		11.80	
	Fillet, lap, edge, and corner	1/8	FVH	20		9.44	
			0	25		11.80	
	Butt	3/16	FVH	25		11.80	
			0	30		14.16	
	Butt	1/4	FVH	30		14.16	
			0	35		16.52	
	Fillet, lap, edge, and corner	3/16, 1/4	FVH	30		14.16	
			0	35		16.52	
	Butt, fillet, lap, edge, and corner	3/8	FVH	35		16.52	
			0	40		18.88	
Nickel and Nickel Alloys		to max for GTAW (3/8 approx.)		10 – 20	1 1/2 to 3 times the argon flow	4.72 – 9.44	
Copper and Copper Alloys		1/16		10 – 15	8 – 12	4.72 – 7.08	3.78 – 5.66
		1/8		14 – 20	10 – 15	6.61 – 9.44	4.72 – 7.08
		3/16	FVH	16 – 22	12 – 18	3.56 – 10.38	5.66 – 8.50
		1/4	0	20 – 30	16 – 25	9.44 – 14.16	3.56 – 11.80
		1/2		25 – 35	20 – 30	11.80 – 16.52	9.44 – 14.16

* Positions – F – Flat, H – Horizontal, V – Vertical, 0 – Overhead

5.6 SELECTING CORRECT GTAW TORCH NOZZLE.

a. Nozzles used on gas tungsten arc welding torches vary in size and method of attachment. The end of the nozzle which attaches to the torch varies in design. This design variation is necessary to permit attachment to different manufacturers' torches.

b. Most nozzles used for GTAW are manufactured from ceramic materials.

c. The diameter of the nozzle closest to the arc or the exit diameter is manufactured in a variety of sizes; see figure 5–24.

d. Manufacturers may put their own distinct part number on each nozzle. In addition, a single digit number is used to identify the exit diameter. This number designates the exit diameter of the nozzle in 1/16 in. (1.6 mm). A number 6 nozzle is:

6 x 1/16 in. = 3/8 in. in diameter or 6 x 1.6 mm = 9.6 mm in diameter

A number 8 nozzle is:

8 x 1/16 in. = 1/2 in. in diameter or 8 x 1.6 mm = 12.8 mm

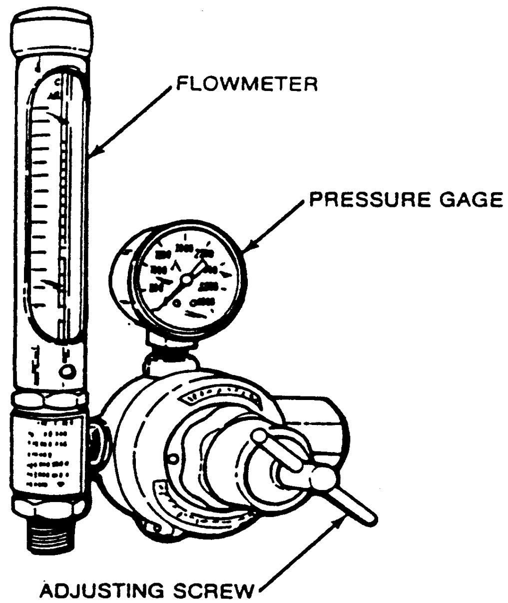


Figure 5–23. Argon Regulator with Flowmeter

e. The diameter of the nozzle must be large enough to allow the entire weld area to be covered by the shielding gas. The action of the shielding gas will vary with a given gas flow rate as the diameter of the nozzle changes. With a gas flow rate of 14 cubic feet/hour (cfh) or 6.61 liters/minute (L/min) and a number 8 nozzle, the gas will flow out of the nozzle slowly and gently. With the same flow rate and a number 4 nozzle, the gas will flow out more rapidly and may be blown away from the joint more quickly. However, a low number nozzle will have to be used in a narrow groove in order to reach the bottom of the joint.

f. The choice of the nozzle size is often a compromise which is necessary to meet the requirements of the job. Small diameter nozzles are often used to permit a constant arc length. As an example, see figure 5–25. In this case, the important root pass is to be welded. The nozzle is constantly touching the sides of the groove as it is rocked back and forth across the root opening. It is also kept in contact with the groove opening as the weld moves forward slowly. This choice of a small nozzle diameter allows the welder to reach the bottom of the groove. It also allows the welder to keep a constant arc length. A higher gas flow may be needed in this case to compensate for the smaller nozzle diameter.

5.7 SELECTING AND PREPARING A TUNGSTEN ELECTRODE.

a. The selection of the correct type and diameter of tungsten electrode is extremely important to performing a successful gas tungsten arc weld. The types of tungsten electrodes are:

(1) Pure tungsten (painted with a green color band).

(2) Tungsten with one or two percent thorium added. These are called thoriated tungsten electrodes (1% yellow band, 2% red band).

(3) Tungsten with from 0.15 to 0.40 percent zirconia added (brown band).

(4) Tungsten with 0.9 to 1–2 percent lanthanium added (black band).

(5) Pure tungsten with a core of tungsten which contains one to two percent thoria. When the core and pure tungsten combine, the percentage of thoria is from 0.35 – 0.55 (blue band).

b. PURE TUNGSTEN ELECTRODES are preferred for AC welding on aluminum or magnesium. They are preferred because they form a ball or hemisphere at the tip when they are heated. This shape reduces current rectification and allows the AC to flow more easily.

c. THORIATED TUNGSTEN ELECTRODES are preferred for DC applications. Thoria increases the electron emissions from a tungsten electrode. The addition of one percent to two percent thoria also keeps the electrode tip from forming a ball. Thoriated electrodes are usually ground to a point or to a near point when used with direct current (DC).

d. If a thoriated electrode is used with AC, it will not form a ball. It will form a number of small projections at the tip. These projections will cause a wild wandering of the arc. Thoriated electrodes shall be used only for direct current GTAW.

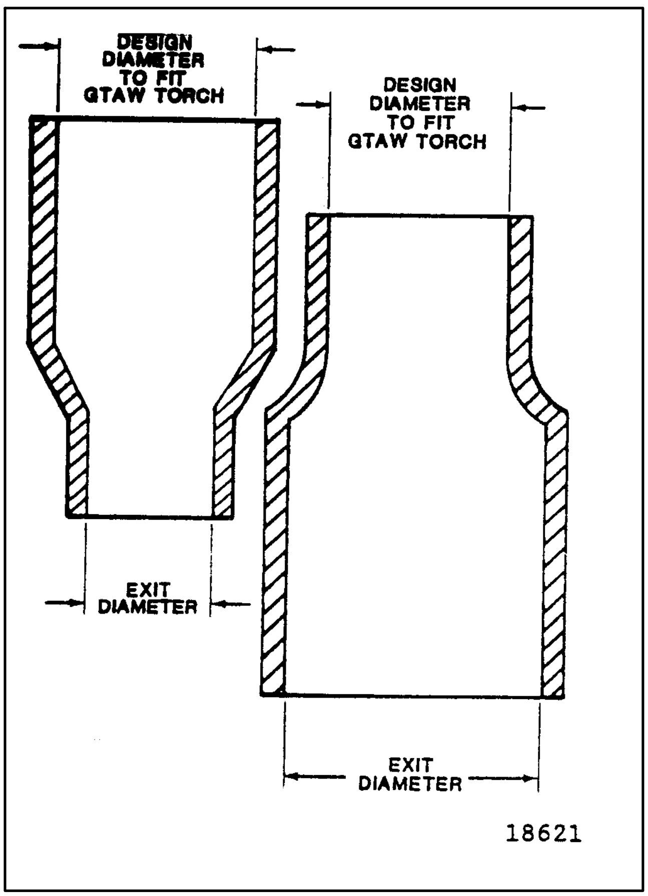


Figure 5-24. Two Different GTAW Torch Nozzles

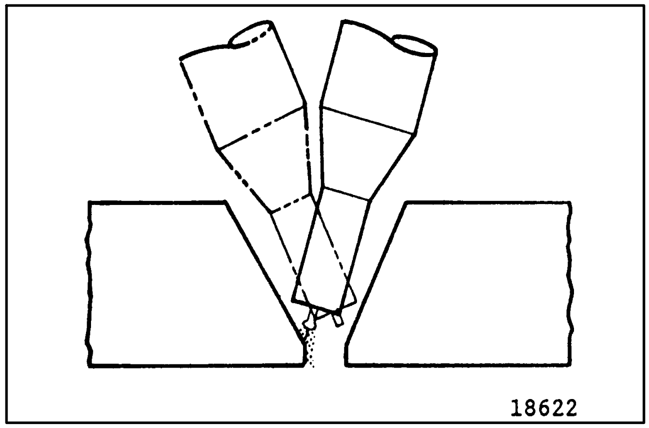


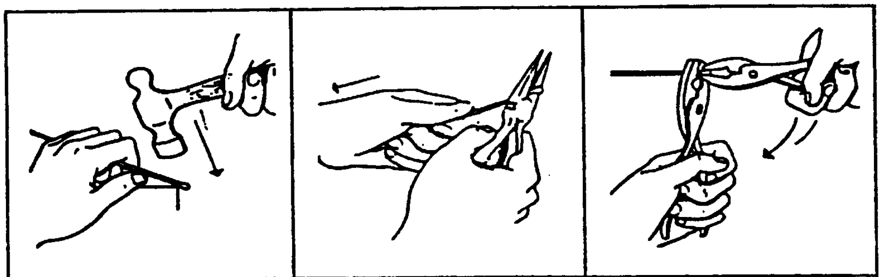
Figure 5-25. Small Exit Diameter

e. A pure tungsten electrode will always form a ball at the tip when used with AC. When used with AC, the pure tungsten electrode is not ground to a point. A ball the same size as the electrode diameter forms when the arc is struck. This ball may be up to one and one half times the size of the electrode diameter, but should never exceed that limit. Above the one and one half times the electrode diameter limit, the tungsten in the ball may melt off and fall into the weld. If the ball on the end of the tip is much larger than the electrode diameter, the current may be set too high.

f. Tungsten electrodes of any type must be protected from contamination. The electrode should not be touched to the base metal, weld metal, or filler metal while it is hot. Such contamination prevents the electrode from emitting or receiving electrons effectively. The end of this electrode must be broken off and reshaped. See figure 5-26 for the proper ways of retipping a contaminated or split electrode.

g. The hot tungsten electrode and metal in the weld area may be contaminated by oxygen and nitrogen in the air and by airborne dirt. To prevent this contamination, a shielding gas is used. The shielding gas is allowed to flow over the electrode and the weld area after the arc is broken. The timing of this shielding gas AFTER FLOW is set on the arc welding machine panel.

h. Table 5-5 lists the operating current range for each type of tungsten electrode. Pure tungsten electrodes used with AC are sometimes ground to a blunt point. The arc is then struck to form a small ball at the tip. This point must not be sharp or the tip may fall into the crater when the ball forms. Thoriated tungsten electrodes are preferred for DC welding applications. They should be ground to a point or to a near point for use with high currents.



HAMMER	PLIERS-SHEARING	PLIERS-BREAKING
For 3/32" and larger	For 1/16" and smaller	For 1/8" and smaller
Hold electrode at an angle over edge of a hard surface with the portion to be broken off projecting. Grip the electrode near the edge. With a hammer, strike projecting end close to supporting surface, directing the blow away from the edge.	Grip electrode between plier cutters at exact point to be removed. Hold pliers level with electrode but at a slight angle. As cutting pressure is applied with pliers, pull back slightly with hand grasping electrode.	Hold electrode in pair of standard pliers with only section to be broken extending beyond jaws. Grasp this projecting portion with other pliers. Break off by bending.

18611

Figure 5–26. Proper Ways to Retip Tungsten Electrodes

Table 5–5. Suggested Current Range for Various Types and Sizes of Tungsten Electrodes[a]

Electrode Diameter		**DCEN (DCSP)**	**DCEP (DCRP)**	**Alternating Current Unbalanced Wave**		**Alternating Current Balanced Wave**	
		A	A	A		A	
in.	mm	EWX–X	EWX–X	EWP	EWX–X	EWP	EWX–X
0.010	0.30	Up to 15	na[b]	Up to 15	Up to 15	Up to 15	Up to 15
0.020	0.50	5–20	na	5–15	5–20	10–20	5–20
0.040	1.00	15–80	na	10–60	15–80	20–30	20–60
0.060	1.60	70–150	10–20	50–100	70–150	30–80	60–120
0.093	2.40	150–250	15–30	100–160	140–235	60–130	100–180
0.125	3.20	250–400	25–40	150–200	225–325	100–180	160–250
0.156	4.00	400–500	40–55	200–275	300–400	160–240	200–320
0.187	5.00	500–750	55–80	250–350	400–500	190–300	290–390
0.250	6.40	750–1000	80–125	325–450	500–630	250–400	340–525

Notes:

a. All are values based on the use of argon gas. Other current values may be employed depending on the shielding gas, type of equipment and application.

b. na = not applicable

x–x Equates to alloyed tungsten

CAUTION

Safety goggles must be worn while performing any grinding operation.

i. Special grinding wheels should be used for pointing tungsten electrodes. These wheels should be used only for grinding tungsten electrodes. Freedom from contamination is essential.

j. Silicon carbide or alumina oxide grinding wheels are preferred. Alumina oxide cuts more slowly, but lasts longer than silicon carbide wheels. Electrodes should be rough ground on an 80 grit grinding wheel. The finish grinding should be done on a 120 grit wheel. A grinding wheel with an open structure is best because it will run cooler and pick up less contamination.

k. After the electrode diameter has been selected, a collet of the same inside diameter must be placed into the torch. The electrode is then placed into the torch collet. An electrode may be adjusted even with the end of the nozzle. It may extend up to 1/2 in. (approximately 13 mm) beyond the nozzle. However, as a general rule, an extension distance equal to one electrode diameter is an average setting. The extension beyond the nozzle is determined by the shape of the joint. A longer extension permits the welder to see the arc crater better. Higher gas flow rates are required with longer extensions in order to protect the electrode from contamination. The extension distance of the electrode generally should not be greater than the exit diameter of the nozzle.

l. Electrodes should be ground in a lengthwise direction. The grinding marks on the tapered area must run in a lengthwise direction. This method on grinding insures the best current carrying characteristics. Figures 5–27 and 5–28 illustrate the suggested method for grinding tungsten electrodes. composite cored, or stranded rod. The filler metal is procured in coils of several hundred feet or in precut lengths. The coiled wire is cut to any desired length by the welder. The pre–cut wire is usually in lengths of 24 or 36 in. (610 or 914 mm).

5.8 SELECTING CORRECT FILLER METAL FOR USE WITH GTAW.

a. Filler metal used for gas tungsten arc welding (GTAW) is generally bare wire. This filler metal is produced in a solid wire form. Corrosion resisting chromium and chromium–nickel steel filler metal comes as a solid, composite cored, or stranded rod. The filler metal is procured in coils of several hundred feet or in pre–cut lengths. The coiled wire is cut to any desired length by the welder. The pre–cut wire is usually in lenghts of 24 or 36 in. (610 or 914 mm).

b. Steel welding rods should not be copper coated as in oxyfuel gas welding. The copper coating will cause spatter which may contaminate the tungsten electrode.

c. The diameter of the most frequently used filler wire varies from 1/16 in. – 1/4 in. (1.59 – 6.35 mm). Smaller wire is readily available in coils down to .015 in (.38 mm) diameter. Precut filler rods are readily available up to 1/4 in. (6.35 mm). The proper filler rod diameters to use when welding various thicknesses of metals are shown in tables 5–6 through 5–10.

5.9 METHODS OF STARTING THE ARC.

a. The gas tungsten arc may be started in one of three ways. These are by touch starting, by the application of a superimposed high frequency, and high voltage starting.

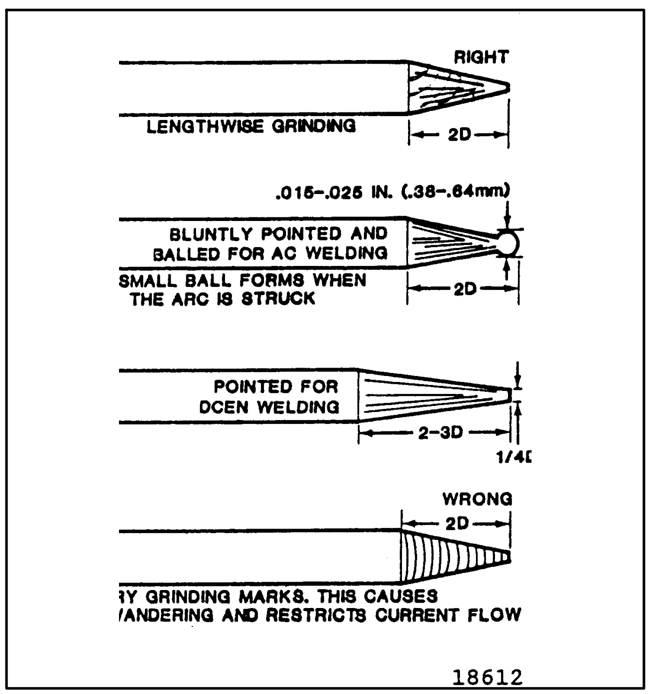


Figure 5–27. Methods of Grinding Tungsten Electrodes

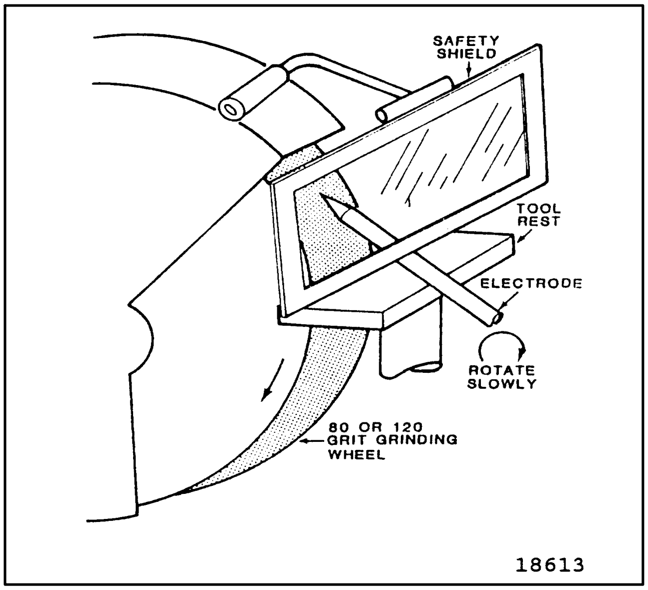


Figure 5–28. Correct Position for Grinding Tungsten Electrode

b. To start the arc, the remote finger or foot operated contactor switch must be depressed. This switch also causes the shielding gas and cooling water to flow prior to starting the arc.

c. When TOUCH STARTING is used, the electrode is touched to the base metal and withdrawn about 1/8 in. (about 3 mm). After a few seconds when the arc is stabilized (running smoothly), the electrode may be brought down to a short arc length of about 1/32 – 3/32 in. (.8 – 2.4 mm). Touching the tungsten electrode to the base metal again may contaminate the electrode.

d. To start the arc using the SUPERIMPOSED HIGH FREQUENCY, place the nozzle on the metal as shown in figure 5–29. With the electrode and nozzle in this position, the contactor switch is turned on to start the high frequency current. The machine contactor switch may be operated by a pedal or manually operated remote switch. Another method of using high frequency start is to hold the electrode horizontally about 1 in. (about 25 mm) above the metal. The electrode is then rotated toward a vertical position. As the electrode comes near the base metal, the high frequency will jump the gap to start the arc. When using direct current, the high frequency will turn off automatically when the arc is stabilized. The high frequency should remain on constantly when using alternating current.

e. HIGH VOLTAGE STARTING is done with a high voltage surge. The electrode is brought close to the base metal as in high frequency starting. When the contactor switch is turned on, a high voltage surge causes the arc to jump and start the arc. After the arc is stabilized, the voltage surge stops automatically.

f. When welding with alternating current, the electrode forms a ball or spherical shape on the end. This ball can be formed before the actual weld begins. To form the ball on the electrode tip, strike the arc on a clean piece of copper. Copper will not melt easily and will not contaminate the electrode readily if a touch occurs. This piece of copper may be 2 in. x 2 in. (roughly 50 x 50 mm) and 1/16 in. (1.59 mm) thick. It should be kept by the welder as a part of the station equipment.

5.10 GAS TUNGSTEN ARC WELDING TECHNIQUES.

a. One advantage of GTAW is that a weld may be made with a small heat affected zone around the weld. Oxy fuel gas and SMAW heat a large area while the metal is raised to the melting temperature. This causes a large heat affected zone and a potentially weaker metal area around the weld.

b. Another advantage of GTAW is that there is no metal transfer through the arc. There is no spattering of metal globules from the arc or crater. The arc action is very quiet and the completed weld is of high quality.

c. GTAW should be done with the lowest current necessary to melt the metal. The highest welding speed possible, which will insure a sound weld, should be used.

d. Once the arc is struck, it is directed to the area to be melted. A puddle or molten pool is formed under the arc and the filler rod is added to fill the pool. The width of the pool, when making stringer beads, should be about 2 – 3 times the diameter of the electrode used. If the bead must be wider, a weaving bead is used. Several stringer beads may also be used to fill a wide groove joint. Sufficient shielding gas must flow to protect the molten metal in the weld area from becoming contaminated.

e. The filler rod must not be withdrawn from the area protected by the shielding gas. If the filler rod is withdrawn while it is molten, it will become contaminated. If it is then melted into the weld, the weld will be contaminated.

f. After the arc is struck, heat a spot until a molten pool forms. The electrode should be held at about a 60–75 degree angle from the work. Hold the filler rod at about a 16–20 degree angle to the work. See figure 5-30. When the molten pool reaches the desired size, add the filler rod to the pool. When the filler rod is to be added, the electrode should be moved to the back of the pool. The filler rod is than added to the forward part of the molten pool. Refer to figure 5-31. This technique of adding the filler metal to the pool may be used for all weld joints in all positions.

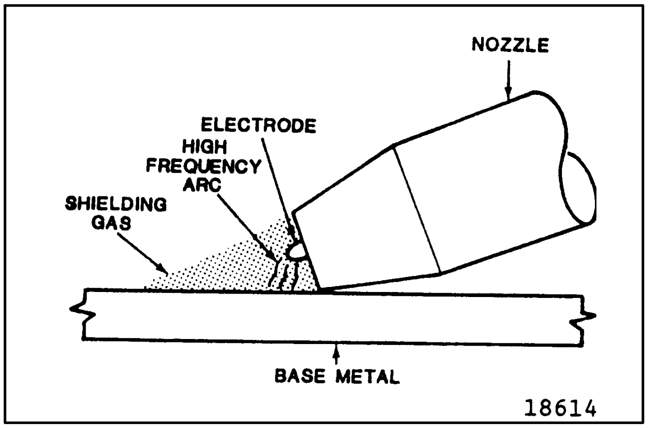


Figure 5-29. Position of Electrode and Nozzle for High Frequency Arc Staring

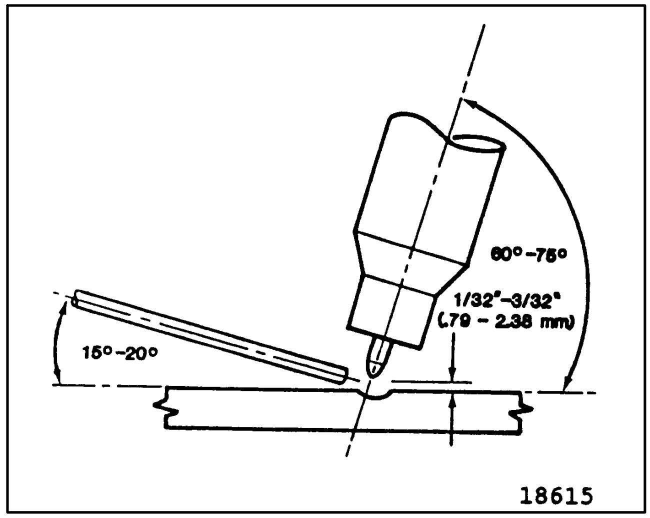


Figure 5-30. Relative Positions of Electrode and Filler Rod When GTAW

Table 5-6. Variables for Manually Welding Mild Steel Using Gas Tungsten Arc and DCEN (DCSP)

Metal Thickness	Joint Type	Tungsten Electrode Diameter	Filler Rod Diameter (If required)	Amperage	Gas		
					Type	Flow CFH	L/Min*
1/16 in. (1.59 mm)	Butt	1/16 in. (1.59 mm)	1/16 in. (1/59 mm	60-70	Argon	15	7.08
	Lap	1/16 in.	1/16 in.	70-90	Argon	15	
	Corner	1/16 in.	1/16 in.	60-70	Argon	15	
	Fillet	1/16 in.	1/16 in.	70-90	Argon	15	
1/8 in. (3.18 mm)	Butt	1/16-3/32 in. (1.59-2.38 mm)	3/32 in. (3.38 mm)	80-100	Argon	15	7.08
	Lap	1/16 in.-3/32 in.	3/32 in.	90-115	Argon	15	
	Corner	1/16 in.-3/32 in	3/32 in.	80-100	Argon	15	
	Fillet	1/16 in.-3/32 in	3/32 in.	90-115	Argon	15	
3/16 in. (4.76 mm)	Butt	3/32 in. (2.38 mm)	1/8 in. (3.18 mm)	115-135	Argon	20	9.44
	Lap	3/32 in.	1/8 in.	140-165	Argon	20	
	Corner	3/32 in.	1/8 in.	115-135	Argon	20	
	Fillet	3/32 in.	1/8 in.	140-170	Argon	20	
1/4 in. (6.35 mm)	Butt	1/8 in. (3.18 mm)	5/32 in. (4.0 mm)	160-175	Argon	20	9.44
	Lap	1/8 in.	5/32 in.	170-200	Argon	20	
	Corner	1/8 in.	5/32 in.	160-175	Argon	20	
	Fillet	1/8 in.	5/32 in.	175-210	Argon	20	

* Liters per minute

Table 5–7. Variables for Manually Welding Aluminum Using the Gas Tungsten Arc Using AC and High Frequency

Metal Thickness	Joint Type	Tungsten Electrode Diameter	Filler Rod Diameter (If required)	Amperage	Gas		
					Type	Flow CFH	L/Min*
1/16 in. (1.59 mm)	Butt	1/16 in. (1.59 mm)	1/16 in. (1/59 mm	60–85	Argon	15	7.08
	Lap	1/16 in.	1/16 in.	70–90	Argon	15	
	Corner	1/16 in.	1/16 in.	60–85	Argon	15	
	Fillet	1/16 in.	1/16 in.	70–100	Argon	15	
1/8 in. (3.18 mm)	Butt	3/32–1/8 in. (2.38–3.18 mm)	3/32 in. (2.38 mm)	125–150	Argon	20	9.44
	Lap	3/32–1/8 in.	3/32 in.	130–160	Argon	20	
	Corner	3/32–1/8 in.	3/32 in.	120–140	Argon	20	
	Fillet	3/32–1/8 in.	3/32 in.	130–160	Argon	20	
3/16 in. (4.76 mm)	Butt	1/8–5/32 in. (3.18–4.0 mm)	1/8 in. (3.18 mm)	180–225	Argon	20	11.80
	Lap	1/8–5/32 in.	1/8 in.	190–240	Argon	20	
	Corner	1/8–5/32 in.	1/8 in.	180–225	Argon	20	
	Fillet	1/8–5/32 in.	1/8 in.	190–240	Argon	20	
1/4 in. (6.35 mm)	Butt	5/32–3/16 in. (4.0–4.76 mm)	3/16 in. (4.76 mm)	240–280	Argon	25	14.16
	Lap	5/32–3/16 in.	3/16 in.	250–320	Argon	25	
	Corner	5/32–3/16 in.	3/16 in.	240–280	Argon	25	
	Fillet	5/32–3/16 in.	3/16 in.	250–320	Argon	25	

Table 5–8. Variables for Manually Welding Stainless Steel Using the Gas Tungsten Arc and DCEN or DCSP

Metal Thickness	Joint Type	Tungsten Electrode Diameter	Filler Rod Diameter (If required)	Amperage	Gas		
					Type	Flow CFH	L/Min*
1/16 in. (1.59 mm)	Butt	1/16 in. (1.59 mm)	1/16 in. (1.59 mm	40–60	Argon	15	7.08
	Lap	1/16 in.	1/16 in.	50–70	Argon	15	
	Corner	1/16 in.	1/16 in.	40–60	Argon	15	
	Fillet	1/16 in.	1/16 in.	50–70	Argon	15	
1/8 in. (3.18 mm)	Butt	3/32 in. (2.38 mm)	3/32 in. (2.38 mm)	66–85	Argon	15	7.08
	Lap	3/32 in.	3/32 in.	90–110	Argon	15	
	Corner	3/32 in.	3/32 in.	66–85	Argon	15	
	Fillet	3/32 in.	3/32 in.	90–110	Argon	15	
3/16 in. (4.76 mm)	Butt	3/32 in. (2.38 mm)	1/8 in. (3.18 mm)	100–125	Argon	20	9.44
	Lap	3/32 in.	1/8 in.	124–150	Argon	20	
	Corner	3/32 in.	1/8 in.	100–125	Argon	20	
	Fillet	3/32 in.	1/8 in.	126–150	Argon	20	
1/4 in. (6.35 mm)	Butt	1/8 in. (3.18 mm)	5/32 in. (4.0 mm)	136–160	Argon	20	9.44
	Lap	1/8 in.	5/32 in.	160–180	Argon	20	
	Corner	1/8 in.	5/32 in.	136–160	Argon	20	
	Fillet	1/8 in.	5/32 in.	160–180	Argon	20	

Table 5–9. Variables for Manually Welding Stainless Steel Using the Gas Tungsten Arc and DCEN or DCSP

Metal Thickness	Joint Type	Tungsten Electrode Diameter	Filler Rod Diameter (If required)	Amperage[1] with Back-up	W/O Backup	Gas		
						Type	Flow CFH	L/Min
1/16 in. (1.59 mm)	All	1/16 in. (1.59 mm)	3/32 in. (2.38 mm)	60	35	Argon	13	6.14
3/32 in. (2.38 mm)	All	1/16 in. (1.59 mm)	1/8 in. (3.18 mm)	90	60	Argon	15	7.08
1/8 in. (3.18 mm)	All	1/16 in. (1.59 mm)	1/8 in. (3.18 mm)	115	85	Argon	20	9.44
3/16 in. (4.76 mm)	All	1/16 in. (1.59 mm)	5/32 in. (4.0 mm)	120	75	Argon	20	9.44
1/4 in. (6.35 mm)	All	3/32 in. (2.38 mm)	5/32 in. (4.0 mm)	130	85	Argon	20	9.44
3/8 in. (9.53 mm)	All	3/32 in. (2.38 mm)	3/16 in. (4.76 mm)	180	100	Argon	25	11.80
1/2 in. (12.7 mm)	All	5/32 in. (4.0 mm)	3/16 in. (4.76 mm)	–	250	Argon	25	11.80
3/4 in. (19.05 mm)	All	3/16 in. (4.76 mm)	1/4 in. (6.35 mm)	–	370	Argon	35	16.52

[1] Use alternating current with a constant high frequency (AC–HF)

Table 5–10. Variables for Manually Welding Deoxidized Copper Using the Gas Tungsten Arc and DCEN or DCSP

Metal Thickness	Joint Type	Tungsten Electrode Diameter	Filler Rod Diameter (If required)	Amperage[1]	Gas		
					Type	Flow CFH	L/Min
1/16 in. (1.59 mm)	All	1/16 in. (1.59 mm)	3/32 in. (2.38 mm)	110 – 150	Argon	15	7.08
1/8 in. (3.18 mm)	All	3/32 in. (2.38 mm)	1/8 in. (3.18 mm)	175 – 250	Argon	15	7.08
3/16 in. (4.76 mm)	All	1/8 in. (3.18 mm)	1/8 in. (3.18 mm)	250 – 325	Argon	18	9.50
1/4 in. (6.35 mm)	All	1/8 in. (3.18 mm)	5/32 in. (4.0 mm)	300 – 375	Argon	22	10.38
3/8 in. (9.53 mm)	All	3/16 in. (4.76 mm)	5/32 in. (4.0 mm)	375 – 450	Argon	25	11.80
1/2 in. (12.7 mm)	All	3/16 in. (4.76 mm)	3/16 in. (4.76 mm)	525 – 700	Argon	30	14.16

[1] Use DCEN DCSP

5.11 SHUTTING DOWN THE GTAW STATION.

a. Each time the arc is broken, the shielding gas continues to flow for a few seconds. This protects the weld metal, electrode, and filler metal from becoming contaminated by the surrounding atmosphere. The gas also continues to flow after the torch or foot operated contactor (off–on) switch is turned off.

b. When welding is stopped for a short time, the GTAW torch is hung on an insulated hook. It may be hung on the hook of a gas economizer valve.

c. If welding is to be stopped for a long period of time, the station should be shut down. After the gas post–flow period, hang up the torch. Shut off the shielding gas cylinder. Turn on the torch or foot operated contactor switch to start the gas flow. Lift the torch from the economizer, if used, to drain the complete shielding gas system of gas. Hang the torch up again. Turn the regulating screw on the regulator counterclockwise to turn it off. Turn the screw in the flowmeter clockwise to shut it off. If the flowmeter is not turned off, the float ball will hit the top of the flowmeter very hard when the regulator is opened again. Turn off the arc welding machine power switch.

5.12 GAS METAL–ARC WELDING (GMAW) EQUIPMENT.

a. General. Gas metal–arc welding is a process in which a consumable, bare wire electrode is fed into a weld at a controlled rate of speed, while a blanket of inert argon gas shields the weld zone from atmospheric contamination.

NOTE

Different types of GMAW welding equipment are available through normal supply channels. Manuals for each type must be consulted prior to welding operations. If for any reason the wire electrode stops feeding, a burn–back will result. With the trigger depressed, the welding contactor is closed, allowing the welding current to flow through the contact tube. As long as the wire electrode advances through the tube, an arc will be drawn at the end of the wire electrode. Should the wire electrode stop feeding while the trigger is still depressed, the arc will then form at the end of the contact tube, causing it to melt off. This is called burn–back.

(1) Three basic sizes of wire electrode may be used: 3/64 inch, 1/16 inch, and 3/32 inch. Any type of metal may be welded provided the welding wire electrode is of the same composition as the base metal.

(2) The unit is designed for use with an ac–dc conventional, constant current type welding power supply. This means that the gasoline engine–driven arc welding machines issued to field units may be used as both a power source and a welding source.

b. A Spool Gun Type GMAW contains a motor and gear reduction unit which feeds the wire electrode from a 4 inch diameter spool holding 1 lb. of electrode wire. The spool is mounted behind the trigger assembly (figure 5–32).

(1) Contact tube. This tube, made of copper, has a hole in the center that is from 0.01 to 0.02–inch larger than the wire electrode being used. The contact tube and the inlet and outlet guide bushings must be changed when the size of the wire electrode is changed.

The contact tube transfers power from the eletrode cable to the welding wire electrode. An insulated lock screw is provided which secures the contact tube in the torch.

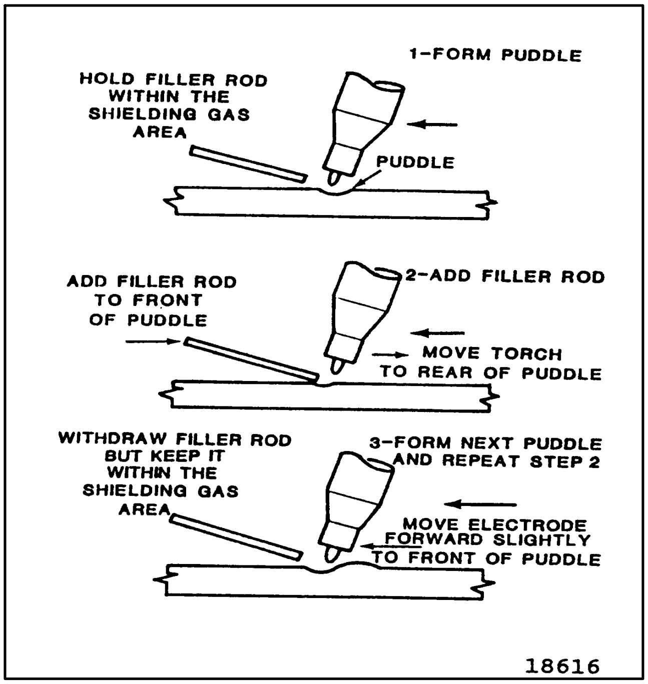


Figure 5–31. Steps Required to Add Filler Metal During GTAW

(2) Nozzle and holder. The nozzle is made of copper to dissipate heat and chrome–plated to reflect the heat. The holder is made of stainless steel and is connected to an insulating material which prevents an arc from being drawn between the nozzle and ground in case the gun comes in contact with the work.

(3) Inlet and outlet guide bushings. The bushings are made of nylon for long wear. They must be changed to suit wire electrode size when the electrode wire is changed.

(4) Pressure roll assembly. This is a smooth roller under spring tension, which pushes the wire electrode against the feed and allows the wire to be pulled from the spool. A thumbscrew applies the tension as required.

(5) Motor. When the inch button is depressed, the current for the motor is supplied by a 110 volt ac–dc source, and the motor pulls the wire electrode from the spool before starting the welding operation. When the trigger is depressed, the actual welding operation starts and the motor pulls the electrode from the spool at the required rate of feed. The current for this motor is supplied by the welding generator.

(6) Spool enclosure assembly (spool gun). This assembly is made of plastic which prevents arc spatter from jamming the wire electrode on the spool. A small window allows a visual check on the amount of wire electrode remaining on the spool.

c. The Wire Feed Type GMAW uses a wire spool mounted behind the Wire Drive Wheels on the DC Welding Machine Power Unit. An adjustable, constant speed motor actuates the Wire Drive Wheels (figure 5–33).

(1) Welding contactor. The positive cable from the dc welding generator is connected to a cable coming out of the welding contactor and the ground cable is connected to the workpiece. The electrode cable and the welding contactor cable are connected between the welding contactor and voltage control box as shown.

(2) Argon gas hose. This hose is connected from the voltage control box to the argon gas regulator on the argon cylinder.

(3) Electrode cable. The electrode cable enters through the welding current relay and connects into the argon supply line. Both then go out of the voltage control box and into the torch in one line.

(4) Voltage pickup cable. This cable must be attached to the ground cable at the work. This supplies current to the motor during welding when trigger is depressed.

(5) Torch switch and grounding cables. The torch switch cable is connected into the voltage control box, and the torch grounding cable is connected to the case of the voltage control box.

d. Figure 5–34 displays the connecting diagram explained below for the Gas Metal Arc Welding Station used with either the Spool Gun Type or the Wire Feed Type GMAW.

5.13 <u>OPERATING THE TORCH.</u>

a. <u>Commencing to Weld</u>.

(1) Press the inch button and allow enough wire electrode to emerge from the nozzle until one–half inch protrudes beyond the end of the nozzle. With the main light switch ON and the argon gas and power sources adjusted properly, the operator may commence to weld.

(2) If welding in the open air, a protective shield must be installed to prevent the argon gas from being blown away from the weld zone.

(3) Pressing the torch trigger sends current down the torch switch cable and through the contactor cable, closing the contactor.

(4) When the contactor closes, the welding circuit from the generator to the welding torch is completed.

(5) As the contactor closes, the argon gas solenoid valve opens, allowing a flow of argon gas to pass out of the nozzle to shield the weld zone.

(6) As the contactor closes, the argon gas solenoid valve opens, allowing a flow of argon gas to pass out of the nozzle to shield the weld zone.

<u>CAUTION</u>

To prevent overloading the torch motor when stopping the arc, release the trigger; never snap the arc out by raising the torch without first releasing the trigger.

(7) Welding will continue as long as the arc is maintained and the trigger is depressed.

b. <u>Setting the Wire Electrode Feed</u>.

(1) A dial on the front of the voltage control box, labeled WELDING CONTROL regulates the speed of the wire electrode feed.

(2) Turning the dial counterclockwise increases the speed of the wire electrode being fed from the spool. This decreases the amount of resistance across the arc and allows the motor to turn faster. Turning the dial clockwise will increase the amount of resistance, thereby decreasing the speed of the wire electrode being fed from the spool.

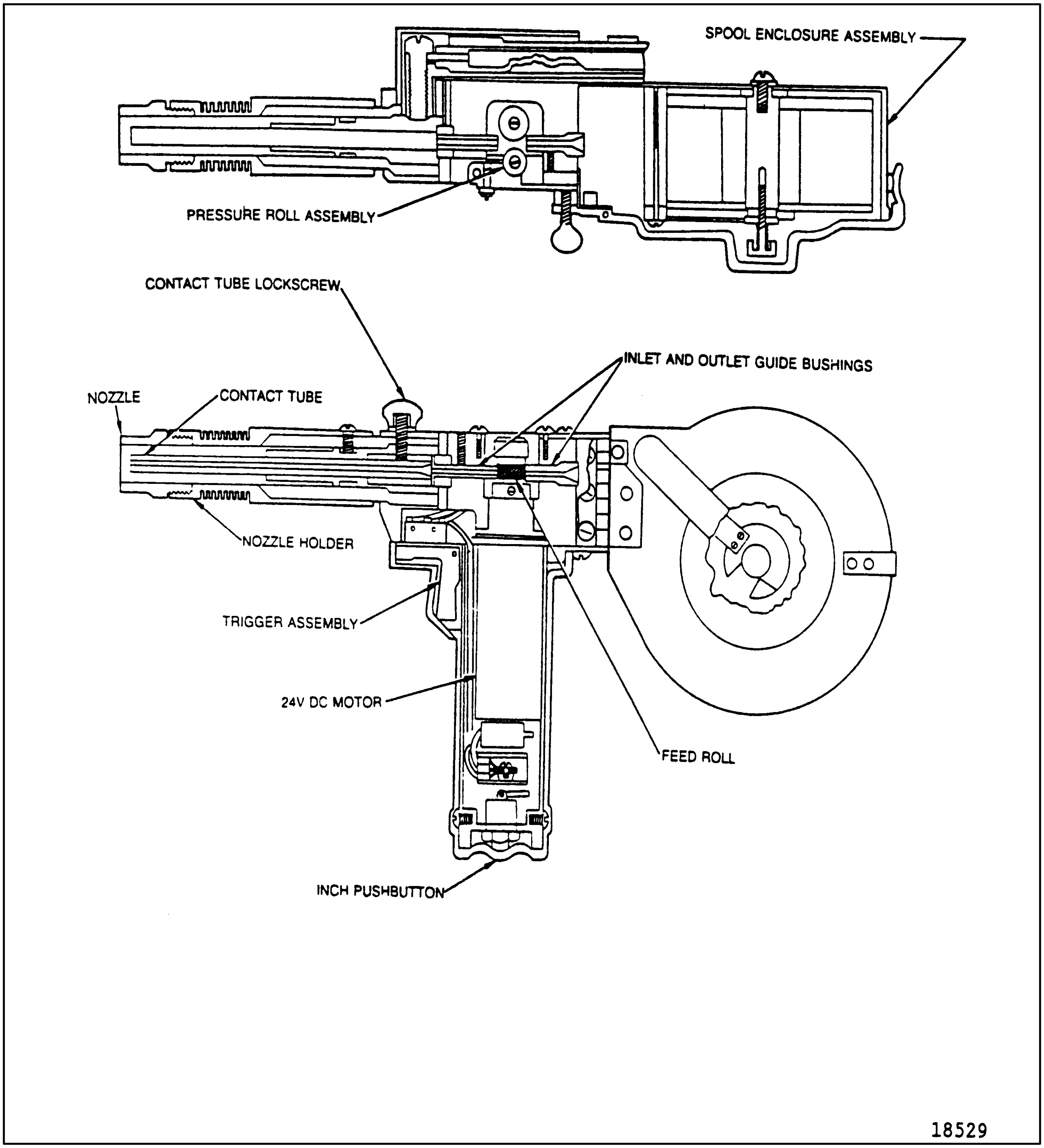


Figure 5–32. Spool Gun Type (GMAW)

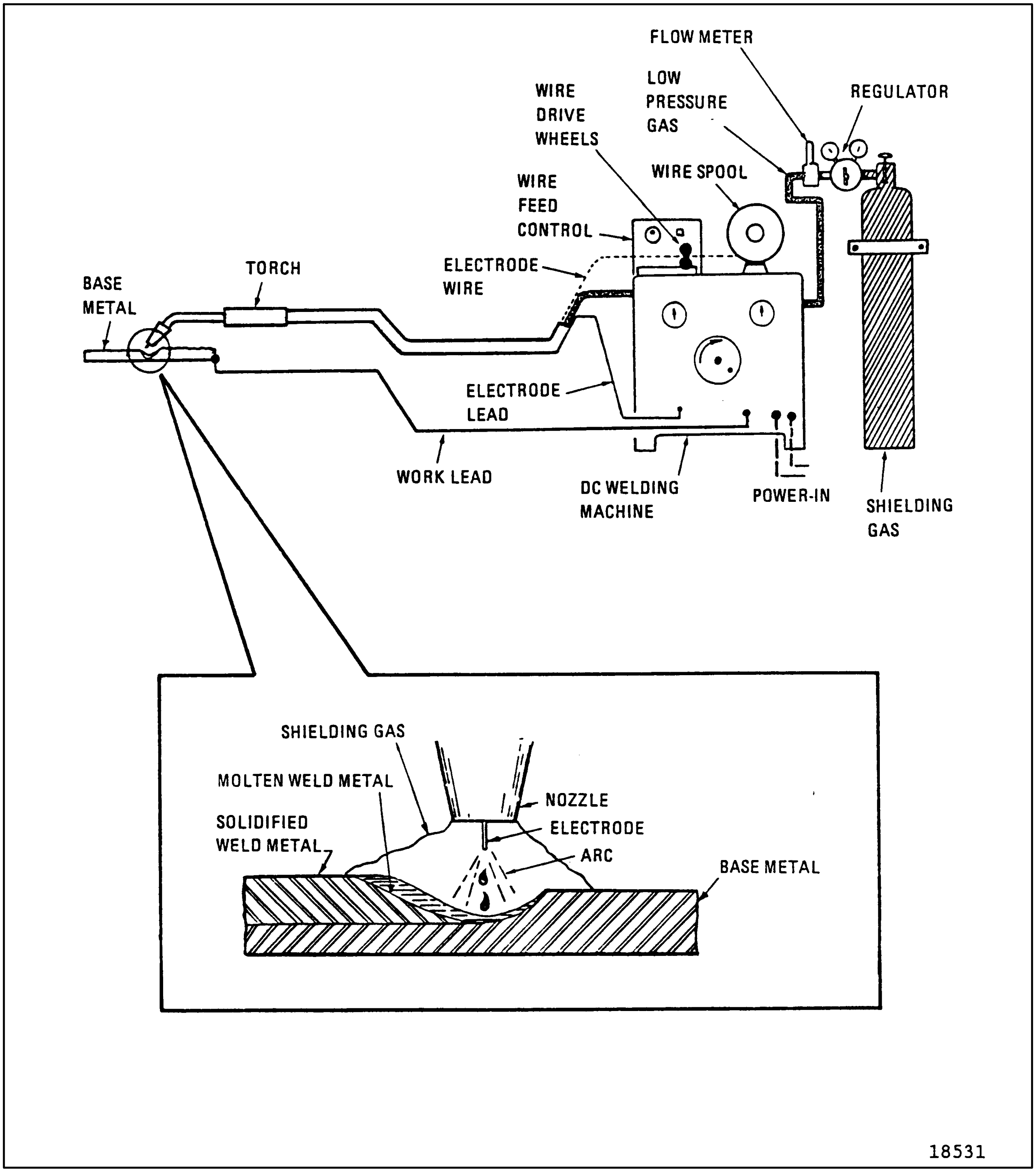


Figure 5–33. Wire Feed Type (GMAW)

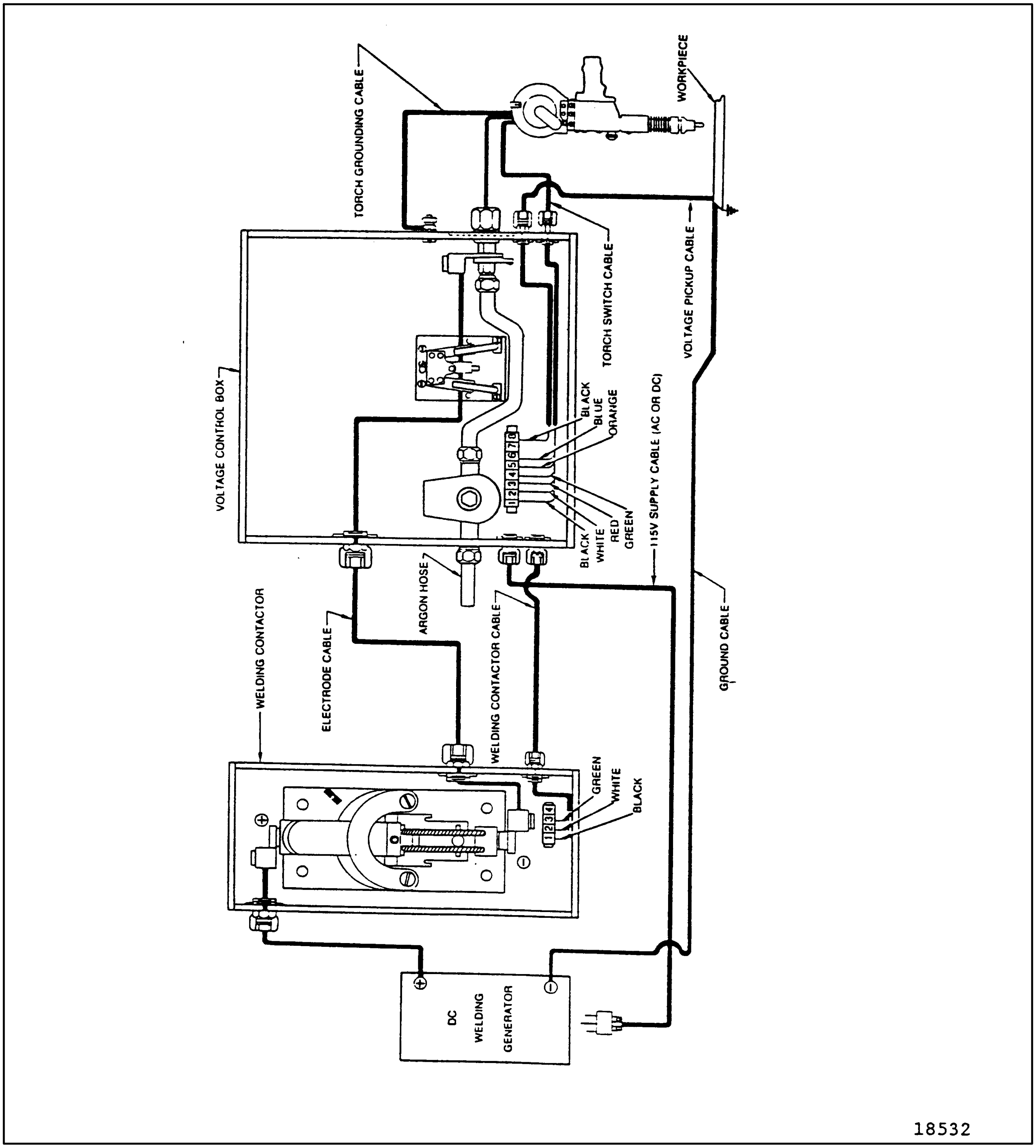


Figure 5–34. Connection Diagram for GMAW

(3) The instant the wire electrode touches the work, between 50 to 100 volts dc is generated. This voltage is picked up by the voltage pickup cable and shunted back through the voltage control box into a resistor. There it is reduced to the correct voltage (24v dc) and sent to the torch motor.

c. Installing the Wire Electrode in Spool Gun.

(1) Open the spool enclosure cover assembly, brake, and pressure roll assembly (figure 5–32).

NOTE

Spooled wire has a tendency to unravel when loosened from the spool.

Maintain a firm grip on the wire during the threading operation.

(2) Unroll and straighten 6 inches of wire electrode from the top of the spool.

(3) Feed this straightened end of the wire electrode into the inlet and outlet bushings; then place the spool onto the mounting shaft.

(4) Close the pressure roller, and secure it in place. Press the inch button, feeding the wire electrode until there is one–half inch protruding beyond the end of the nozzle.

d. Installing Wire Electrode in Feed Type Machine (figure 5–33).

(1) Cut off any portion of the free end of the wire which is not straight. Ensure that the cut end is free from rough surfaces to permit proper feeding.

(2) Loosen the knob on the drive roll pressure adjustment, pivot the pressure adjustment free of the cover, and pivot the pressure gear assembly away until it is in an open position.

(3) Feed the wire through the inlet wire guide, past drive rolls, and on into the outlet wire guide. Feed approximately 4 in. (102 mm) of wire into outlet wire guide.

(4) Close the gear cover making sure the teeth on the pressure gear mesh with teeth on the drive gear. The welding wire must also be in the grooves of the drive rolls.

(5) Pivot the pressure adjustment knob until washer on the pressure adjustment is seated on top of the gear cover.

(6) Turn the pressure adjustment knob in a clockwise direction until the drive rolls are tight against the welding wire. Do not overtighten. Further adjustment to attain desired clamping pressure can be made after the welding power source and wire feeder are put into operation.

(7) Draw the gun cable out straight.

(8) Turn the Line Disconnect Switch and the welding power source POWER switch to the ON position. If the welding power source has spot welding capabilities, place the Selector switch located on the welding power source front panel, in the CONTINUOUS position.

(9) Press and hold the gun trigger until the wire extends about 1/4 in. (6 mm) out of the contact tube.

(10) Cut off excess wire to 1/4 in. (6 mm) length with side cutters.

e. Setting the Argon Gas Pressure.

(1) Flip the argon switch on the front of the voltage control panel to the MANUAL position.

(2) Turn on the argon gas cylinder valve, and set the appropriate pressure on the regulator.

(3) When the proper pressure is set on the regulator, flip the argon switch to the AUTOMATIC POSITION.

(4) With the argon switch in the MANUAL position, the argon gas continues to flow. With the argon switch in the AUTOMATIC position, the argon gas flows only when the torch trigger is depressed and stops flowing when the torch trigger is released.

f. Generator Polarity. The generator is set on reverse polarity. When set on straight polarity, the torch motor will run in reverse, withdrawing the wire electrode and causing a very severe burn–back.

g. Reclaiming Burned–Back Contact Tubes. When burn–backs occur, a maximum of 3/8 inch may be filed off. File a flat spot on top of the guide tube, place a drill pilot on the contact tube, and then drill out the contact tube. For a 3/64 inch contact tube, use a No. 46 or 47 drill bit.

h. Preventive Maintenance.

(1) Keep all weld spatter cleaned out of the inside of the torch. Welding in the vertical or overhead positions will cause spatter to fall down inside the torch nozzle holder and restrict the passage of the argon gas. Keep all hose connections tight.

(2) To replace the feed roll, remove the name plate on top of the torch, the flathead screw and retainer from the feed roll mounting shaft, and the contact ring and feed roll. Place new feed roll on the feed roll mounting shaft, making certain that the pins protruding from the shaft engage the slots in the feed roll. Reassemble the contact ring and nameplate.

5.14 RESISTANCE WELDING EQUIPMENT.

a. General. The standard types of equipment used for resistance welding are composed of these principal elements:

(1) An electrical circuit with a transformer and current regulator, with a secondary circuit to conduct the welding current to the electrodes.

(2) The mechanical equipment for holding the work and applying the required pressure.

(3) The control and timing devices.

b. Spot Welding.

(1) A spot welding machine with its essential operating elements for manual operation is shown in figure 5–35. In this machine the electrode jaws are extended in such a manner as to permit a weld to be made at a considerable distance from the edge of the base metal sheet. The electrodes, are composed of a copper alloy which are assembled in such a manner that considerable force or squeeze may be applied to the metal during the welding process.

(2) In aluminum spot welding conventional machines may be used, however the best results are obtained only if certain refinements are incorporated into these machines. Some of these desirable features are: ability to handle high current for short weld times; precise electronic control of current and length of time it is applied; rapid follow up of the electrode force by use of anti–friction bearings and lightweight low inertia heads; high structural rigidity of the welding machine arms, holders, and platens to minimize deflection under the high electrode forces used for aluminum, and to reduce magnetic deflections; a variable or dual force cycle to permit forging the weld nugget; slope control to permit a gradual build–up and tapering off of the welding current; postheat current to allow slower cooling of the weld nugget; good cooling of the Class I electrodes to prevent tip pickup or sticking. Refrigerated cooling is often helpful.

c. Projection Welding. The projection welding dies or electrodes have flat surfaces with larger contacting areas than spot welding electrodes. The effectiveness of this type of welding depends on the uniformity of the projections or embossments on the base metal with which the electrodes are in contact (figure 5–36).

d. Upset and Flash Welding. Both of these processes can be performed on the same type of machine. The metals that are to be joined serve as electrodes.

e. Seam Welding. Several types of machines are used for seam welding, the type used depending on the service requirements. In some machines the work is held in a fixed position and a wheel type electrode is passed over it. Portable seam welding machines use this principle. In the traveling fixture type seam welding machine the electrode is stationary and the work is moved.

5.15 RESISTANCE WELDING.

a. General. Resistance welding is a type of welding process in which the workpieces are heated by the passage of an electric current through the area of contact. Such processes include spot, seam, projection, upset and flash welding.

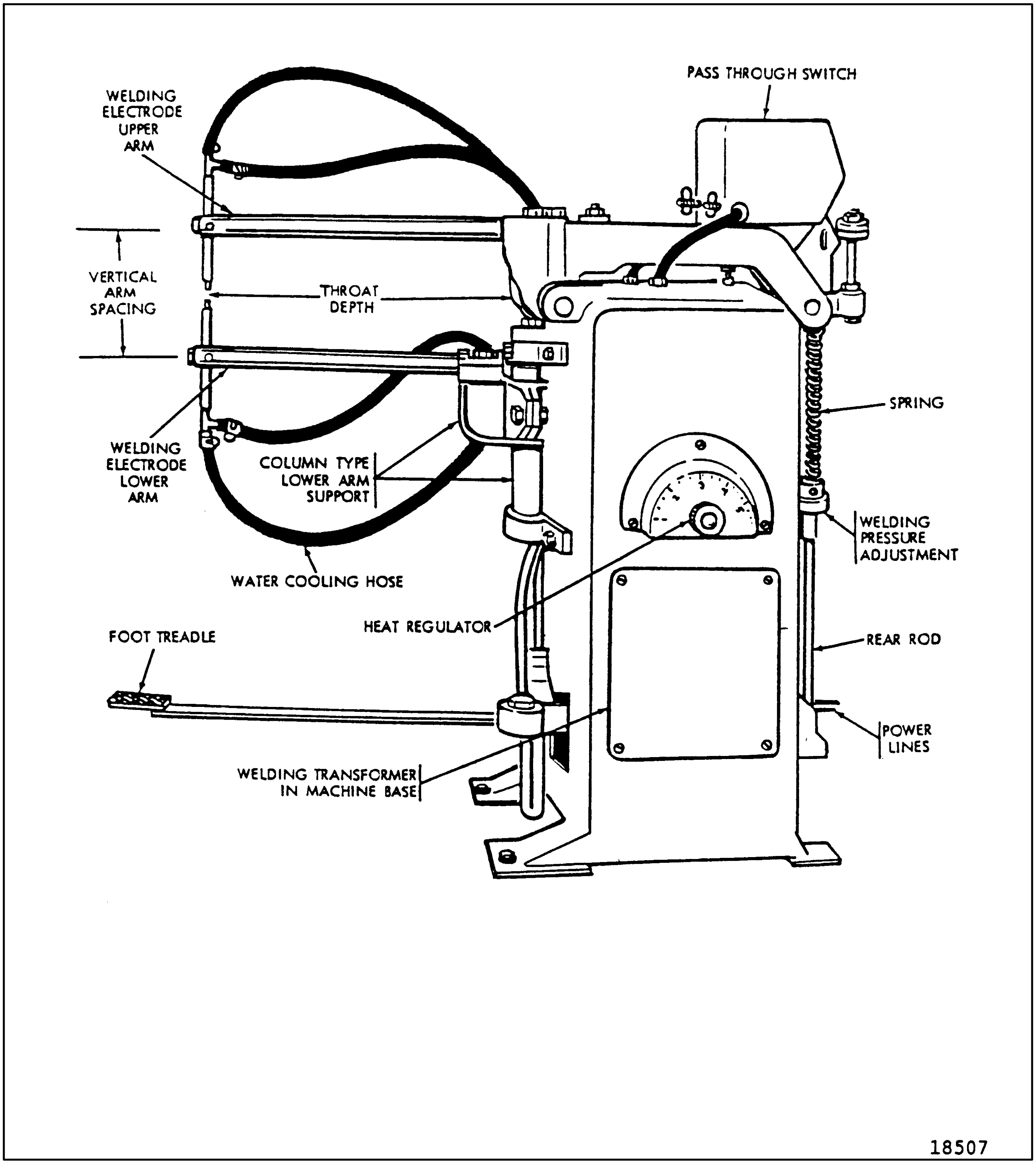


Figure 5–35. Resistance Spot Welding Machine and Accessories

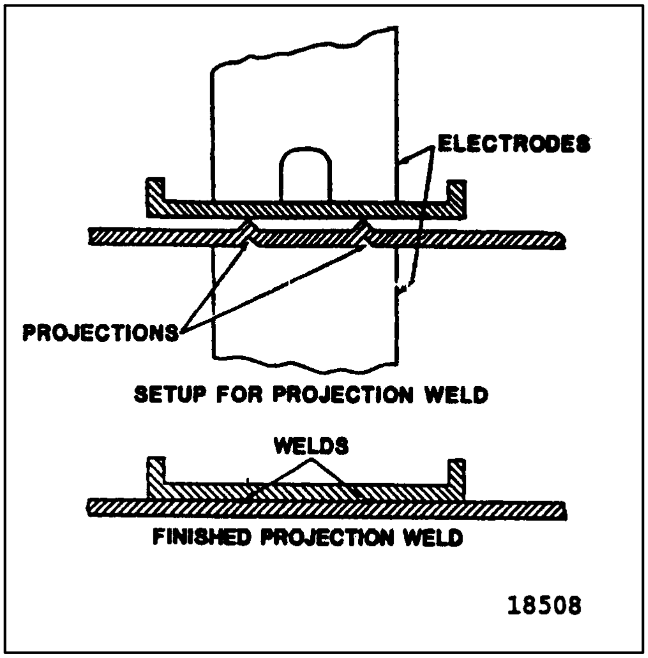


Figure 5–36. Projection Welding

b. Resistance Welding Processes.

(1) Spot Welding. This is a resistance welding process wherein coalescence is produced by the heat obtained from resistance to the flow of electric current through the workpieces, which are held together under pressure by electrodes. The size and shape of the individually formed welds are limited primarily by the size and contour of the electrodes. Spot welding is particularly adaptable to thin sheet metal construction and has many applications in this type of work. The spot welding principle is illustrated in figure 5–37.

(2) Roll Spot Welding. This is a resistance welding process wherein separate spot welds are made without retracting the electrodes. This is accomplished by means of circular electrodes which are in continuous contact with the work.

(3) Seam Welding. This is a resistance welding process wherein coalescence is produced by the heat obtained from resistance to the flow of electric current through the workpieces, which are held together under pressure by rotating circular electrodes. The resulting weld is a series of overlapping spot welds made progressively along a joint. Lapped and flanged joints in cans, buckets, tanks, mufflers, etc., are commonly welded by this process.

(4) Projection Welding. This is a process wherein coalescence is produced by the heat obtained from resistance to the flow of electric current through the workpieces, which are held together under pressure by electrodes. The resulting welds are localized at predetermined points by the design of the parts to be welded. This localization is usually accomplished by projections, embossments, or intersections. A method of localization is illustrated in figure 5–36. This process is commonly used in the assembly of punched, formed, and stamped parts.

(5) Upset Welding. This is a resistance welding process wherein coalescence is produced simultaneously over the entire area of abutting surfaces or progressively along a joint by the heat obtained from resistance to the flow of electric current through the area of contact of these surfaces. Pressure is applied before heating is started and is maintained throughout the heating period. Upsetting is accompanied by expulsion of metal from the joint (figure 5–38).

c. Welding Procedures.

(1) The operation of spot, seam, and projection welding involves the use of electric current of proper magnitude for the correct length of time. The current and time factors must be coordinated so that the base metal within a confined area will be raised to its melting point and then resolidified under pressure. The temperature obtained must be sufficient to insure fusion of the base metal elements but not so high that metal will be forced from the weld zone when the pressure is applied.

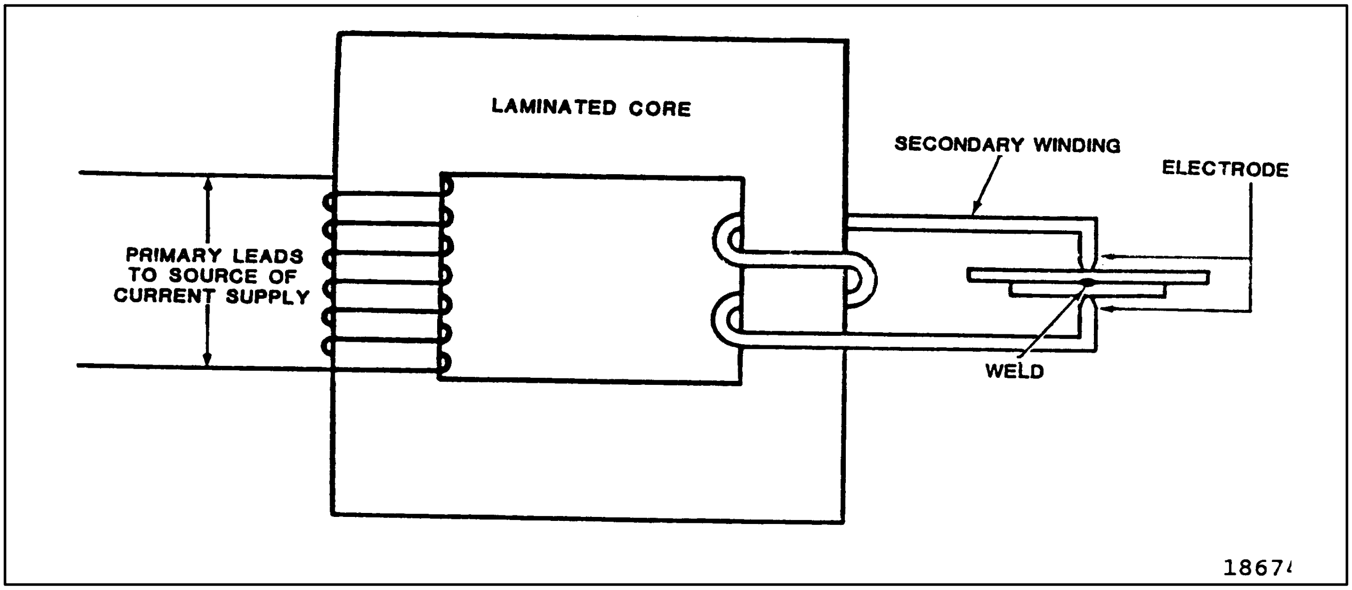


Figure 5-37. Schematic Diagram of Resistance Spot Welder

(2) In upset welding (figure 5-38), the surfaces to be welded are brought into close contact under pressure and the welding heat is obtained from resistance to the flow of current through the area of contact of the abutting surfaces. When a sufficiently high temperature is obtained, welding of the surfaces is achieved by upsetting with the application of high pressure.

d. Spot Welding Magnesium.

(1) General. Magnesium can be joined by spot, seam, or flash welding but spot welding is the most widely used. Spot welding is used mostly on assemblies subject to low stresses and on those not subjected to vibration. The welding of dissimilar alloys by the spot welding process should be avoided, especially if they are alloys with markedly different properties.

(2) Welding Current.

(a) General. Either alternating current or direct current can be used for spot welding magnesium. High currents and short weld duration are required, and both alternating current and direct current spot welders have sufficient capacity and provide the control of current that is necessary in the application of this process.

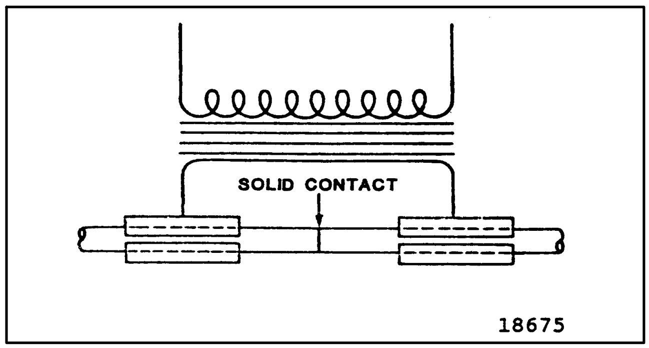


Figure 5-38. Schematic Diagram of Upset Welder

(b) Alternating current machines. The alternating current spot welding machines equipped with electronic synchronous timers, heat control, and phase shifting devices to control weld timing and current are suitable for the welding of magnesium. Three types of machines are used; single-phase, three-phase, and dry-disk rectifier type.

(c) Direct current machines. The electrostatic condenser discharge type is the most widely used direct current machine for magnesium welding. The line demand for this type of equipment may be as high as 500 kva when welding sheets approximately 0.125 inch thick. Electromagnetic machines are also used. They require lower pressure applied by the electrodes during welding than the electrostatic equipment.

(3) Electrodes. Electrodes for spot welding magnesium should be made of high–conductivity copper alloys conforming to Resistance Welder Manufacturer' s Association specifications. Hard–rolled copper can be used where special offset electrodes are desired. Electrodes should be water cooled but never to the point where condensation will take place. Intermittent water flow, supplied only when the weld is made, assists in the maintenance of a constant tip temperature. The most common tips are dome–ended with tip radii of curvature ranging from 2 to 8 inches, depending on sheet thickness. Four degree flat tips are frequently used. Flat tips with diameters from 3/8 to 1 1/4 inches are used on the side of the work where the surface is to be essentially free of marks. Contact surfaces of the electrodes must be kept clean and smooth.

(4) Cleaning. Magnesium sheets for spot welding should be purchased with an oil coating rather than a chrome pickle finish. Pickled surfaces are hard to clean for spot welding, because of the surface etch. Satisfactory cleaning can be accomplished by either chemical or mechanical methods. Mechanical cleaning is used where the number of parts to be cleaned does not justify a chemical cleaning setup. Stainless steel wool, stainless steel wire brushes, or aluminum oxide cloth are used for this purpose. Ordinary steel wool and wire brushes leave metallic particles and should not be used, because the magnetic field created in the tip will attract these particles. Chemical cleaning is recommended for high production. It is economical and provides consistently low surface resistance, resulting in more uniform welds and approximately double the number of spot welds between tip cleanings. The allowable time between cleaning and welding is also much longer. Chemically cleaned parts can be welded up to 100 hours after cleaning, while mechanically cleaned parts should be welded at once.

(5) Machine Settings. Spot welding is a machine operation requiring accurate current, timing, and welding force and therefore, the adjustment of the welding machine to the proper setting is the most important step in the production of strong consistent welds. The welding machine manufacturer's operating instructions should be followed closely. Recommended spacing and edge distances are given in table 5–11.

(6) Pressure. Welding pressures are usually established first, using the lower current or capacitance and voltage values recommended. High pressure provides greater latitude in the currents that can be used for the production of sound welds but may be limited by excessive sheet separation or the size of the electrodes. After approximating the pressure, the proper weld time, voltage, and weld current or capacitance should be determined to obtain welds of the desired size and strength. If the maximum weld size is too small or cracking is encountered, it may be necessary to increase the pressure and current, or possibly the weld time.

After all the settings are fixed, the hold time may need adjustment to make certain that pressure is maintained on the weld until solidification is complete. Insufficient hold time will result in porous welds and is normally indicated by a cracking sound during the contraction of the weld. Trial welds should be made in material of the same gage, alloy, hardness, and surface preparation as the metal to be welded. Test welds between strips crossed at right angles are useful for determining proper welding conditions, because they can be easily twisted apart.

e. Spot and Seam Welding Titanium.

(1) Spot and seam welding procedures for titanium and titanium alloys are very similar to those used on other metals. Welds can be made over a wide range of conditions and special shielding is not required. The short welding times and proximity of the surfaces being joined prevent embrittlement of the welds by contamination from the air.

(2) The spot and seam welding conditions which have the greatest effect on weld quality are welding current and time. With variations in these conditions, the diameter, strength, penetration, and indentation of the spot welds change appreciably. Electrode tip radius and electrode force also have some effect on these properties. For all applications, welding conditions should be established depending on the thicknesses being welded and the properties desired.

(3) Most experience in spot welding is available from tests on commercially pure titanium. In these tests, the welding conditions have varied considerably, and it is difficult to determine if there are optimum spot welding conditions for various sheet gages. One of the major problems encountered is excessive weld penetration. However, penetration can be controlled by selecting suitable welding current and time.

(4) Experience with some of the high strength alpha–beta alloys has shown that postweld heat treatments are beneficial to spot and seam weld ductility, but procedures have not been developed to heat treat these welds in the machines. When necessary, furnace heat treatments or an oxyacetylene torch may be used to heat treat spot welds.

(5) Specifications have been established for spot and seam welds in commercially pure titanium. The quality control measures of these specifications for stainless steel (MIL–W–6858) are used. Suitable minimum edge distances and spot spacing are listed in table 5–12. These are the same spot spacings and edge distances specified for spot welds in steel.

Table 5–11. Magnesium Spot Weld Data

B & S gage No.	Spot spacing (inch)	Minimum edge distance (inch)
24	0.50	0.125
18	0.70	0.187
14	1.00	0.250
12	1.25	0.375
8	1.50	0.625

Table 5–12. Commercially Pure Titanium Spot Weld Data

B & S gage No.	Spot Spacing (inch)	Minimum edge distance (inch)
0.008	0.187	0.125
0.012	0.250	0.125
0.016	0.312	0.187
0.020	0.375	0.187
0.025	0.437	0.250
0.030	0.500	0.250
0.035	0.562	0.250
0.042	0.625	0.312
0.050	0.750	0.312
0.062	0.875	0.312
0.078	1.000	0.312
0.093	1.125	0.375
0.125	1.135	0.500
* Values used when not specified in drawings.		

SECTION VI. GENERAL PRINCIPLES OF WELDING AND CUTTING

6.1 ELECTRIC ARC WELDING PROCESS AND TECHNIQUES.

NOTE

Authority to weld on a particular aircraft, aircraft part or any support equipment must be obtained before any welding/brazing operation can be attempted. Authorization can be found in applicable maintenance manuals and directives.

6.1.1 Characteristics of the Electric Arc. (SMAW).

a. Weld Metal Deposition.

(1) General. In metal–arc welding a number of separate forces are responsible for the transfer of molten filler metal and molten slag to the base metal. Among these forces are those described in (a) through (f) below.

(a) Vaporization and condensation. A small part of the metal passing through the arc, especially the metal in the intense heat at the end of the electrode, is vaporized. Some of this vaporized metal escapes as spatter but most of it is condensed in the weld crater which is at a much lower temperature. This occurs with all types of electrodes and in all welding positions.

(b) Gravity. Gravity affects the transfer of metal in flat position welding. In other positions, smaller electrodes must be used to avoid excessive loss of weld metal, as the surface tension is too low to retain a large volume of molten metal in the weld crater.

(c) Pinch effect. The high current passing through the molten metal at the tip of the electrode sets up a radial compressive magnetic force that tends to pinch the molten globule and detach it from the electrode.

(d) Surface tension. This is the force that holds the filler metal and the slag globules in contact with the molten base or weld metal in the crater. It has little to do with the transfer of metal across the arc but is an important factor in retaining the molten weld metal in place and in the shaping of weld contours.

(e) Gas stream from electrode coatings. Gases are produced by the burning and volatilization of the electrode covering and are expanded by the heat of the boiling electrode tip. The velocity and movement of this gas stream tend to give the small particles in the arc a movement away from the electrode tip and into the molten crater on the work.

(f) Carbon monoxide evolution from electrode. According to this theory of metal movement in the welding arc, carbon monoxide is evolved within the molten metal at the electrode tip, causing miniature explosions which expel molten metal away from the electrode and toward the work. This theory is substantiated by the fact that bare wire electrodes made of high purity iron or ”killed steel” (i.e., steel that has been almost completely deoxidized in casting) cannot be used successfully in the overhead position. The metal transfer from electrode to the work, the spatter, and the crater formation are, in this theory, caused by the decarburizing action in molten steel.

b. Arc Crater.

(1) Arc craters are formed by the pressure of expanding gases from the electrode tip (arc blast), forcing the liquid metal toward the edges of the crater. Also, the higher temperature of the center, as compared with that of the sides of the crater, causes the edges to cool first. Metal is thus drawn from the center to the edges forming a low spot.

6.1.2 Welding Current, Voltage, and Adjustments.

a. The selection of the proper welding currents and voltages depends on the electrode size, plate thickness, welding position, and welder’s skill. Electrodes of the same size can withstand higher current and voltage values in flat position welding than in vertical or overhead welding. Since several factors affect the current and voltage requirements, data provided by welding equipment and electrode manufacturers should be used. For initial settings, see table 6–1 and 6–2.

Table 6-1. E60XX Series Electrodes with suggested metal thickness applications and amperage ranges

Suggested Metal Thickness		Electrode Size		E6010 and E6011	E6012	E6013	E6020	E6022	E6027
in.	mm	in.	mm						
1/16 & less	1.16 & less	1/16	1.6		20-40	20-40			
1/16-5/64	1.6-2.0	5/64	2.0		25-60	25-60			
5/64-1/8	2.0-3.2	3/32	2.4	40-80	35-85	45-90			
1/8-1/4	3.2-6.4	1/8	3.2	75-125	80-140	80-130	100-150	110-160	125-185
1/4-3/8	6.4-9.5	5/32	4.0	110-170	110-190	105-180	130-190	140-190	169-240
3/8-1/2	9.5-12.7	3/16	4.8	140-215	140-240	150-230	175-250	170-400	210-300
1/2-3/4	12.7-19.1	7/32	5.6	170-250	200-320	210-300	225-310	370-520	250-350
3/4-1	19.1-25.4	1/4	6.4	210-320	250-400	250-350	275-375		300-420
1-up	25.4-up	5/16	8.0	275-425	300-500	320-430	340-450		375-475

Table 6-2. E70XX Series Electrodes with suggested metal thickness applications and amperage ranges

Suggested Metal Thickness		Electrode Size		E7014	E7015 and E7016	E7018	E7024 and E7028	E7027	E7048
in.	mm	in.	mm						
5/64-1/8	2.0-3.2	3/32*	2.4*	80-125	65-110	70-100	100-145		
1/8-1/4	3.2-6.4	1/8	3.2	110-160	100-150	115-165	140-190	125-185	80-140
1/4-3/8	6.4-9.5	5/32	4.0	150-210	140-200	150-220	180-250	160-240	150-220
3/8-1/2	9.5-12.7	3/16	4.8	200-275	180-255	200-275	230-305	210-300	210-270
1/2-3/4	12.7-19.1	7/32	5.6	260-340	240-320	260-340	275-365	250-350	
3/4-1	19.1-25.4	1/4	6.4	330-415	300-390	315-400	335-430	300-420	
1-up	25.4-up	5/16*	8.0*	390-500	375-475	375-470	400-525	375-475	

Note: When welding vertically up, currents near the lower limit of the range are generally used.

*: These diameters are not manufactured in the E7028 classification.

b. In preparation for welding, the machine must be adjusted to provide proper welding conditions for the size and type of electrode to be used. These adjustments include proper polarity, current, and voltage settings. Dual control machines make possible control of both voltage and current delivered to the arc. In single control units, current is controlled manually while the voltage is adjusted automatically.

c. After the welding machine has been properly adjusted, the exposed end of the electrode should be gripped in the electrode holder so the entire fusible length can be deposited, if possible, without breaking the arc. In some cases, in welding with long electrodes, the electrode is bared and gripped in the center. Carbon and graphite electrodes should be gripped short of the full length to avoid overheating the entire electrode.

6.1.3 Starting the Arc.

WARNING

If the electrode becomes frozen to the base metal during the process of starting the arc, all work to free the electrode when the current is on should be done with the welding shield covering the eyes.

a. General.

(1) Two methods are used for starting the arc, the striking or brushing method (figure 6-1) and the tapping method (figure 6-2). In both methods the arc is formed by short circuiting the welding current between the electrode and the work surface. When the arc is struck a surge of high current causes both the end of the electrode and a small spot of the base metal beneath the electrode to melt, instantly causing the two molten metals to puddle, completing the weld.

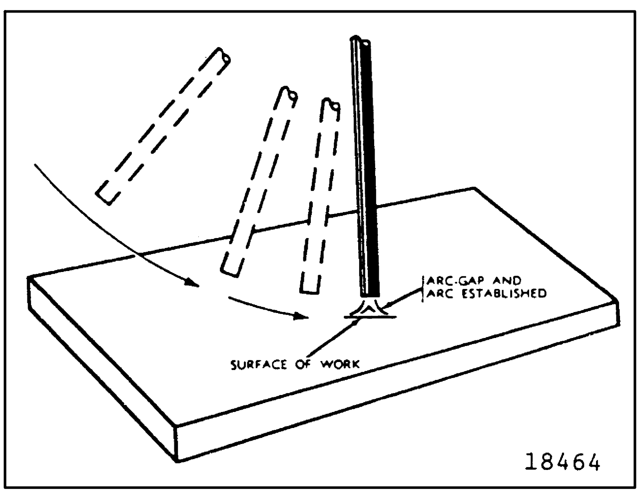


Figure 6-1. Striking or Brushing Method of Starting the Arc

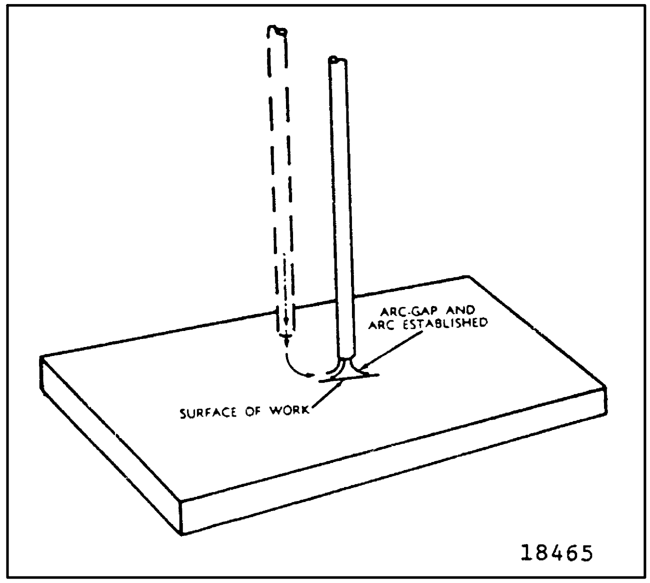


Figure 6-2. Tapping Method of Starting the Arc

(2) In the striking or brushing method the electrode is brought to the surface of the work in a lateral motion similar to striking a match. As soon as the electrode touches the surface, the electrode is raised to establish the arc (figure 6-1). The arc length or gap between the electrode and the work should be approximately equal to the diameter of the electrode. When the proper arc length is obtained a sharp crackling sound is heard.

(3) In the tapping method the electrode is held in a vertical position to the work and tapped, or bounced, on the work surface (figure 6-2). Upon contact, the electrode is raised approximately the diameter of the electrode to establish the proper arc length.

(4) If the electrode is raised too slowly with either of the above arc starting methods the electrode will freeze to the base metal. If this occurs, the electrode can usually be freed by a quick sideways twist to snap the end of the electrode from the base metal. If twisting does not dislodge the electrode, stop the welding machine, remove the holder from the electrode, and free the electrode with a light chisel blow.

(5) With some electrodes, known as contact electrodes, the coating is an electrical conductor, and the arc is normally struck by holding the electrodes in contact with the work. The end of the electrode is held against the base metal and sufficient current passes through the coating to establish

the arc. The arc length is held constant by maintaining this contact, which is possible because the coating has a melting point lower than the metal core of the electrode. The surface contact of this coated electrode, as it melts, forms a deep cut which prevents the electrode from freezing and also shields the arc.

b. Breaking the Arc.

(1) Two procedures, as described below, are used to break the arc when changing electrodes or stopping the weld for any purpose.

(a) In manual welding, when changing electrodes, if the weld is to be continued from the crater the arc is shortened and the electrode moved quickly sideways to break the arc. When the weld is resumed, it is started at the forward, or cold end of the crater, moved backward over the crater, and then forward again to continue the weld.

(b) In manual semi–automatic welding, where filling or partial filling of the crater is required, the electrode is held stationary for a sufficient time to fill the crater and then withdrawn until the arc breaks.

c. AC Welding.

(1) In ac welding, the electrode does not have to touch the workpiece to start the arc. The superimposed high frequency current jumps the gap between the welding electrode and the work, thus establishing a path for the welding current to follow. The striking or brushing method is used to start the arc, with the difference that contact is not made during the swing.

(a) The arc can be struck on the workpiece itself or on a heavy piece of copper or scrap steel and then carried to the starting point of the weld. Do not use a carbon block for starting the arc, as the electrode becomes contaminated, causing the arc to wander.

6.1.4 Improper Arc Control.

a. Maladjustments.

(1) The effects of improper current and welding speed control and the effect on the welding bead are shown in figure 6–3 and table 6–3.

Table 6–3. Effects of Maladjustment of Welding Current and Speed on the Bead Characteristics

Operating Conditions	Arc Sound	Electrode melting Rate	Crater Appearance	Bead Appearance	Depth of Fusion	Spatter
High Current	Explosive sounds with pronounced cracking	Flux coating melts rapidly and irregularly	Deep, long, and irregular	Wide with low, flat crown, some under cutting	Deep and good	Very pronounced large drops
Low Current	Irregular crackling	Flux coating melts slowly	Shallow and small	Rounded high crown, some over lap	Slight and irregular	Slight
High welding speed	Sharp crackling sound	Balanced for good welding	Long and shallow	Narrow, irregular, some under cutting	Very slight and incomplete	Slight
Low welding speed	Sharp crackling sound	Balanced for good welding	Long, wide, and shallow	Wide, high crown, excessive overlap	Good	Some due to over heating
Correct welding conditions	Sharp crackling sound	Balanced and uniform for good welding	Rather deep and uniform	Good fusion, no undercut, no overlap	Deep and good	Very slight

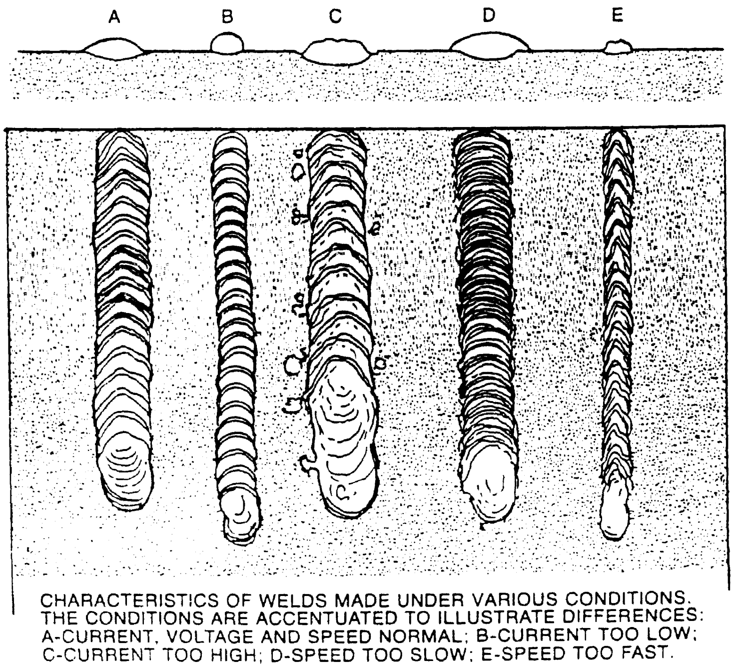


Figure 6-3. Effects of Maladjustments and Weld Bead Characteristics

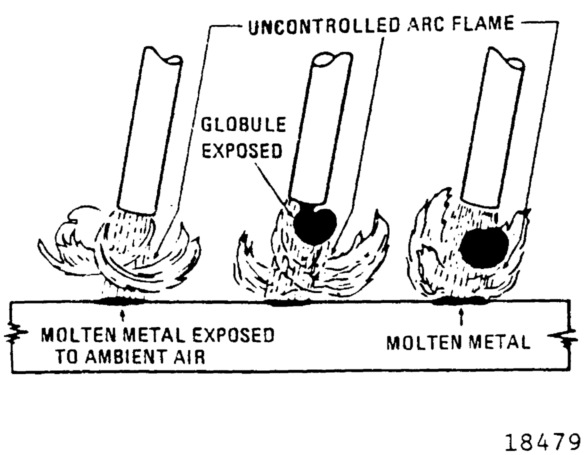


Figure 6-4. Characteristics of a Long Arc

b. Long Arc.

(1) When welding with a long arc the protecting arc flame, as well as the molten globule at the end of the electrode, will whirl and oscillate from side to side (figure 6-4). The fluctuating flame will permit the molten base metal to become oxidized or burned before the molten metal of the electrode reaches the base metal. The direction of the molten filler metal, as it passes through the arc, will be difficult to control and a considerable portion will be lost as spatter. The long arc melts the electrode quickly, but the metal is not always deposited at the desired point. The long arc causes poor penetration, excessive overlap, and burned or porous metal in the weld, as shown in figure 6-5.

c. Correct Arc.

(1) In welding with the short arc, which is the desired procedure, the molten metal leaving the electrode passes through the arc under good protection from the atmosphere by the enveloping arc flame. With this arc better control of the filler metal is obtained and a better quality of weld metal results (figure 6-6). The short arc provides maximum penetration, better physical properties in the weld, and deposits the maximum amount of metal at the point of weld.

d. Very Short Arc.

(1) A very short arc is as undesirable as a long arc since it will produce much spatter, frequently freeze, and make continuous welding difficult. The results of welding with a very short arc are similar to those of the long arc (figure 6-4).

e. Arc Blow.

(1) A characteristic of dc welding is arc blow, which is the occasional dancing of the arc forward and backward or side to side. This is caused by the magnetic field built up in the workpiece as a result of the flow of current. This magnetic field in the metal becomes crowded as the arc nears the end of the workpiece and this distortion of the field deflects the arc from its normal path and makes it difficult to control (figure 6–7).

(2) Arc blow may be reduced by carefully clamping the work to the table in several places. When welding large items it may be desirable to move the ground clamp or cable as the weld progresses.

(3) If the current flow changes direction rapidly, as in ac welding, the magnetic field will also change directions very rapidly, and this change will cancel the arc blow effect and stabilize the arc.

6.1.5 Welding Beads.

a. As the arc is struck, metal melts off the end of the electrode and is deposited in a molten puddle on the work and the electrode is shortened. This causes the arc to increase in length unless the electrode is fed downward as fast as it is melted off and deposited. Before moving forward, the arc should be held at the starting point for a short time to insure good fusion and to allow the bead to build up slightly. With the welding machine adjusted for proper current and polarity, good weld beads can be made by maintaining a short arc and welding in a straight line with constant speed.

b. For welding beads, the electrode in theory should be held at 90 degrees to the base metal (A, figure 6–8). However, in order to obtain a clearer view of the molten puddle, crater, and arc, the electrode should be tilted between 5 and 15 degrees toward the direction of travel (B, figure 6–8).

c. Proper arc length cannot be accurately judged by the eye but can be recognized by sound. The typical sharp crackling sound (table 6–3) should be heard during the time the electrode is moved down to and along the surface of the work.

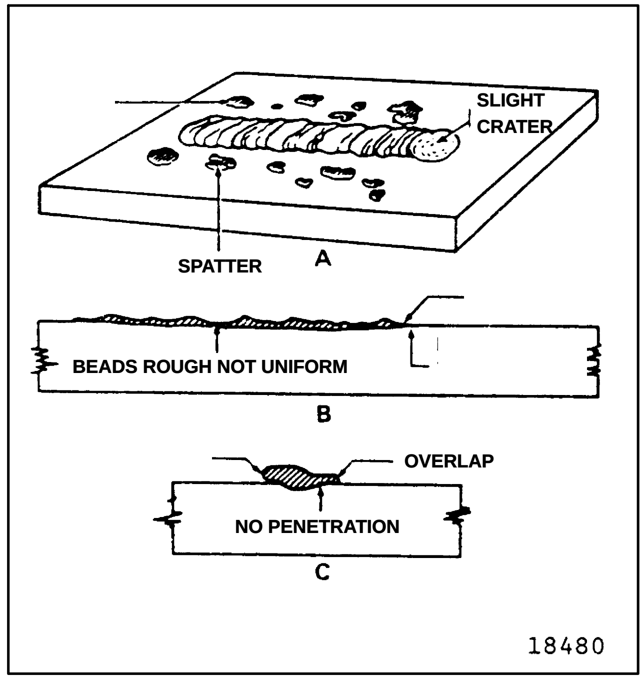


Figure 6–5. Defects in Weld Due to Long Arc

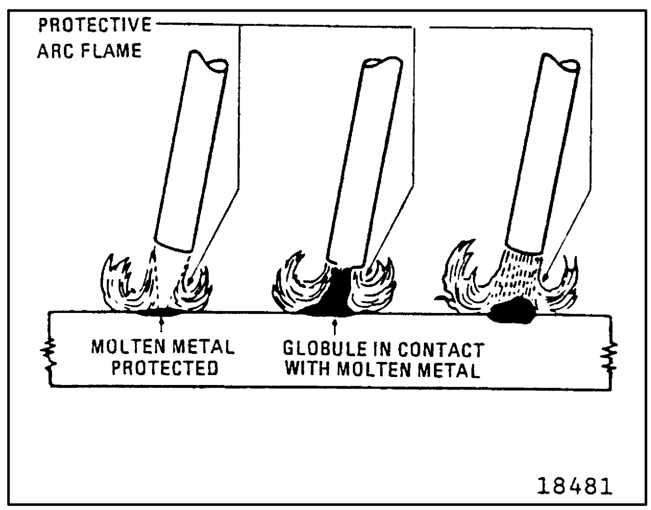


Figure 6–6. Characteristics of an Arc of Correct Length

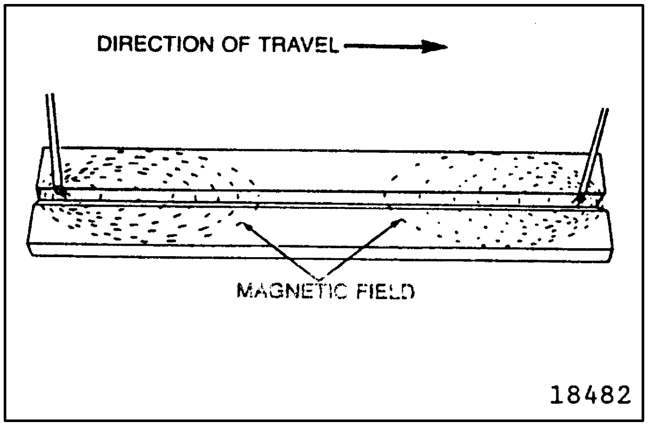


Figure 6-7. Arc Blow

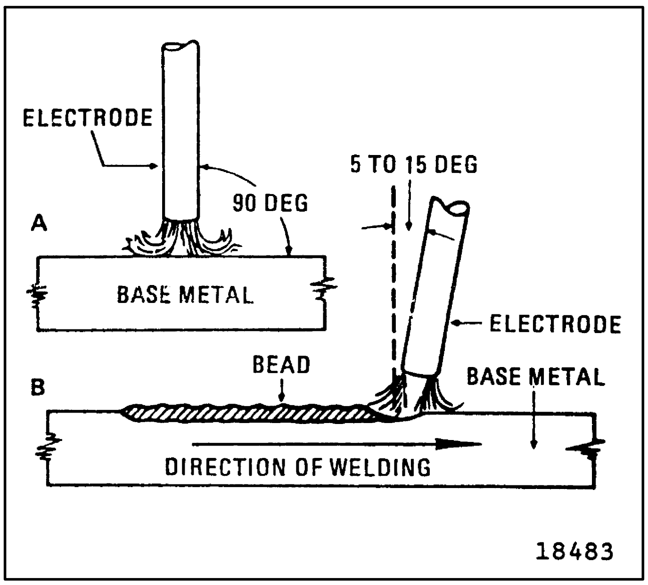


Figure 6-8. Position of Electrode in Making Bead

d. A properly made weld bead (figure 6-9) should leave little spatter on the surface of the work, and the arc crater or depression in the bead as the arc is broken should be approximately 1/16 inch deep (B, figure 6-9), varying slightly with the size of electrode and plate thickness. The bead metal should be built up slightly but without weld metal overlap on the top surface, which would indicate poor fusion.

e. In some situations it is more economical to repair machined parts by building up worn surfaces with weld material, rather than replacing the parts. The built-up surface is then machined to the required size. This process is called surface buildup or padding, and is done by depositing several layers of beads, usually at right angles to each other (figure 6-10), until the necessary thickness is attained. Surface buildup can be performed with either oxyacetylene (brass or steel), arc, or gas shielded arc welding processes. Each bead deposited must overlap each preceding bead by 1/4 of the bead width (figure 6-11).

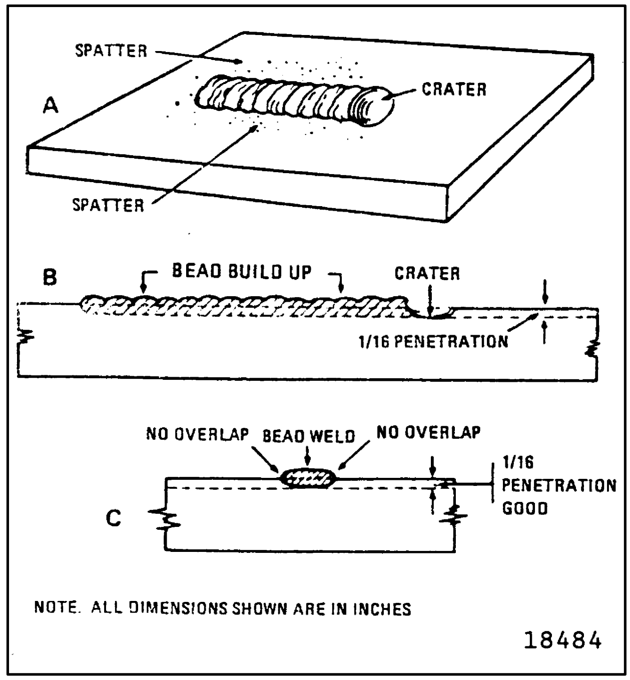


Figure 6-9. Properly Made Weld Beads

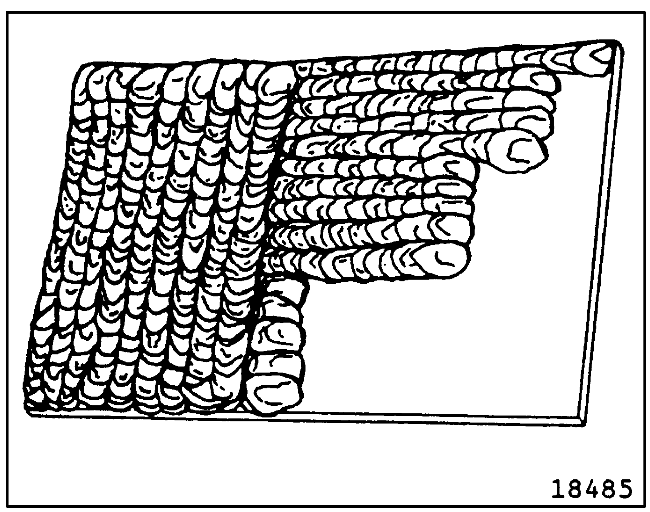


Figure 6-10. Padding Weld Beads

6.1.6 Flat Position Welding.

a. Butt Joints in Flat Position.

(1) A butt joint is used to weld plates having surfaces in approximately the same plane. Several forms of joints are used to make butt welds in the flat position and most of these are shown in figure 6–12.

(2) Plates 1/8 inch thick or less can be welded in one pass; no special edge preparation is necessary. Plates 1/8 to 3/16 inch thick can be welded with no edge preparation by running a weld bead on both sides of the joint. Tack welds should be used to keep the plates aligned. The electrode motion is the same as that used in making a weld bead (paragraph 6.1.5).

(3) In welding 1/4 inch or heavier plates the edge of the plate should be prepared by beveling or by U or V grooving (figure 6–12), whichever is more applicable. Single or double bevels may be used depending on the thickness of the plate being welded. The first bead should be deposited to seal the space between the two plates and weld the root of the joint. This layer must be thoroughly cleaned of slag before the second layer of metal is deposited. In making multipass welds (figure 6–13) the second, third, and fourth layers are deposited with a weaving motion of the electrode and each layer must be cleaned before the next layer is deposited. Any of the weaving motions illustrated in figure 6–14 may be used depending on the type and size of the electrode used.

(4) In the weaving motion, the electrode should be oscillated or moved uniformly from side to side, with a slight hesitation at the end of each oscillation and, as in welding beads, the electrode should be inclined 5 to 15 degrees in the direction of the welding. If the weaving motion is not properly performed, undercutting will occur as shown in figure 6–15. Excessive welding speed will also cause undercutting and poor fusion at the edges of the weave bead

b. Butt Joints in Flat Position With Backing Strips.

(1) Backup, or backing strips, as they shall be referred to in this manual, are used when welding 3/16 inch or heavier plates to obtain complete fusion at the root of the weld, provide better control of the arc, and act as a cushion for the first bead or layer of weld metal. The edges of the plates to be welded are prepared in the same manner as required for welding without backing strips. Backing strips approximately l inch wide and 3/16 inch thick are used for plates up to 3/8 inch thick and backing strips l 1/2 inches wide and 1/4 inch thick for plates over 3/8 inch thick. The backing strips are tack welded to the base of the joint as shown in figure 6–16.

(2) The joint should be completed by adding layers of metal as described in subparagraph a(3) and (4) above.

(3) After the joint is completed, the backing strip can be ”washed away” with a cutting torch and a seal bead may be applied along the root of the weld, if necessary.

c. Plug and Slot Joints.

(1) Plug and slot welds are used to join two overlapping plates by depositing metal to fill a hole or slot which extends through the upper plate. Joints of this type are shown in figures 6–17 and 6–18.

(2) Slot welds are used in butt straps to join casehardened armor plate edges from the back or soft side. Plug welds are used to fill holes in plates and to join overlapping plates. Both of these welds are used to join plates where it is impossible to join them by other methods.

(3) A continuous fillet weld is made to obtain good fusion between the side walls of the hole or slot and the surface of the lower plate. The procedure for this fillet weld is the same as that required for lap welds and the hole or slot is then filled in to provide additional strength in the weld.

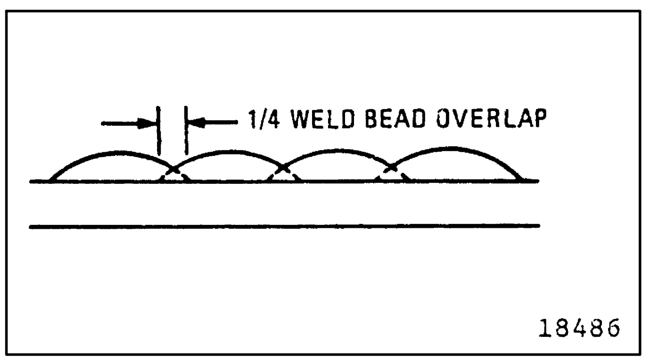


Figure 6–11. Weld Bead Overlap

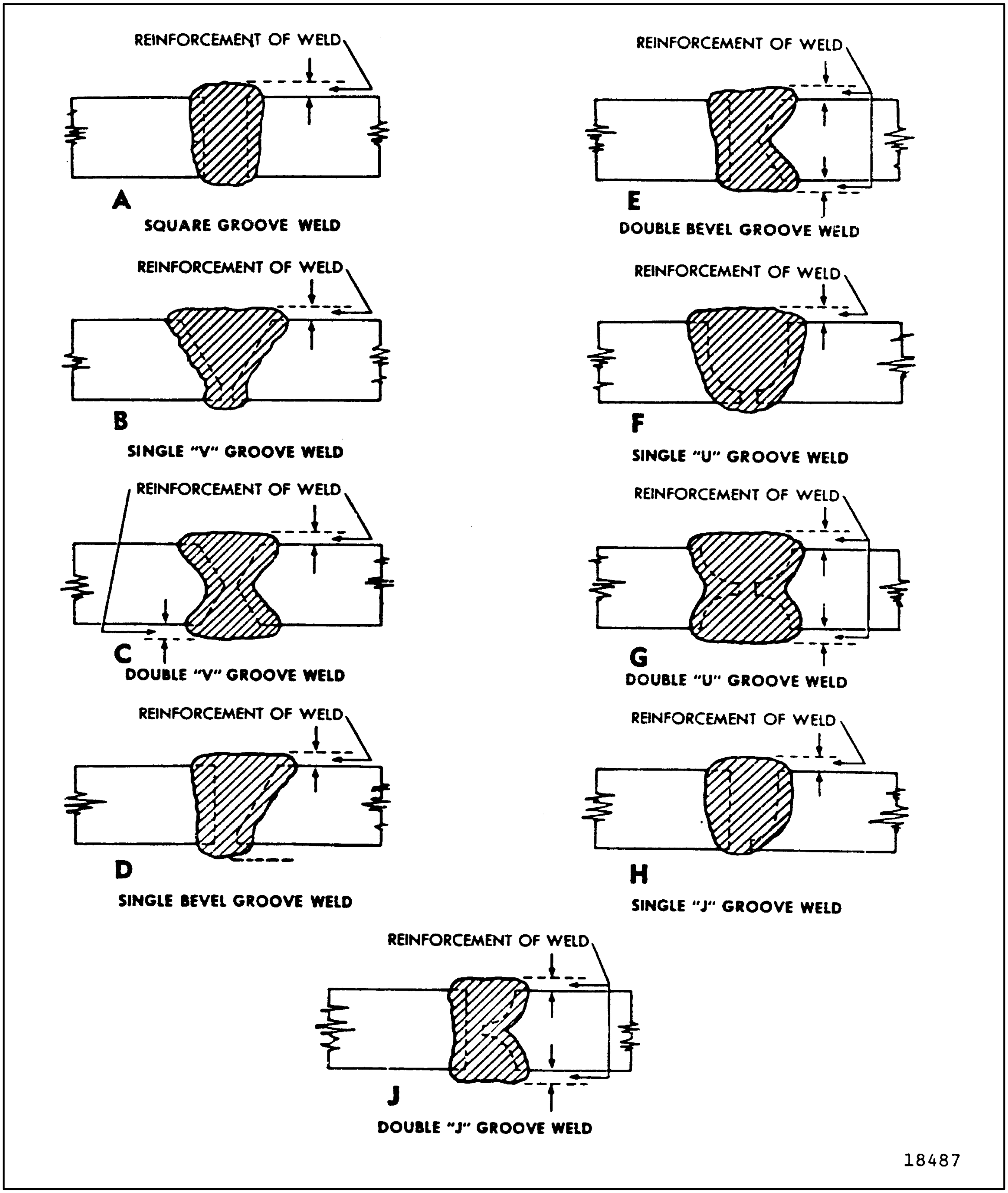


Figure 6-12. Butt Joints in Flat Position

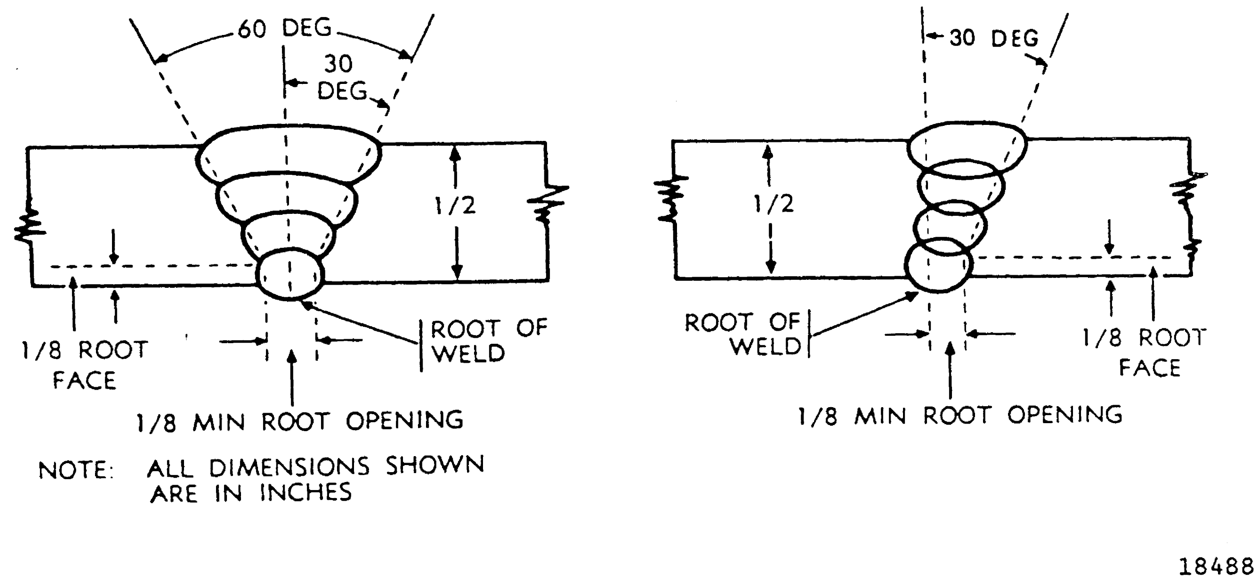


Figure 6-13. Butt Welds with Multipass Beads

(4) The plug weld procedure may also be used to remove bolts or studs twisted off flush with the surface of the part. A nut somewhat smaller than the bolt or stud size is centered on the bolt or stud to be removed. A heavy coated electrode is then lowered into the nut and an arc struck on the exposed end of the broken bolt or stud. The nut is then welded to the bolt or stud and sufficient metal is added to fill the hole. The broken bolt or stud can then be removed with a wrench.

6.1.7 Horizontal Position Welding.

a. Tee Joints.

(1) In making tee joints in the horizontal position, the two plates are located approximately at right angles to each other in the form of an inverted T. The ends of the vertical plate are tack welded to the surface of the horizontal plate as shown in figure 6-19.

(2) A fillet weld is used in making the tee joint and the correct arc (paragraph 6.1.4c) is necessary to provide good fusion at the root and along the legs of the weld (A, figure 6-20). The electrode should be held at a 45 degree angle to the two plate surfaces and inclined approximately 15 degrees in the direction of welding (B, figure 6-20).

(3) Light plates can be secured with a fillet weld of one pass with little or no weaving of the electrode. Welding of heavier plates may require two or more passes, in which each successive pass is made in a semicircular weaving motion as illustrated in figure 6-21. There should be a slight pause at the end of each weave so as to obtain good fusion between the weld and base metals without undercutting.

(4) A fillet welded joint on a 1/2 inch plate or heavier can be made by depositing string beads in sequence, as shown in figure 6-22.

(5) Chain intermittent or staggered intermittent fillet welding (figure 6-23) is used for long tee joints. Fillet welds of this type are used where high weld strength is not required. In this type of weld the short welds are arranged so that the joint is equal in strength to a fillet weld along the entire length of a joint from one side only. Warpage and distortion are held to a minimum in chain intermittent type welds.

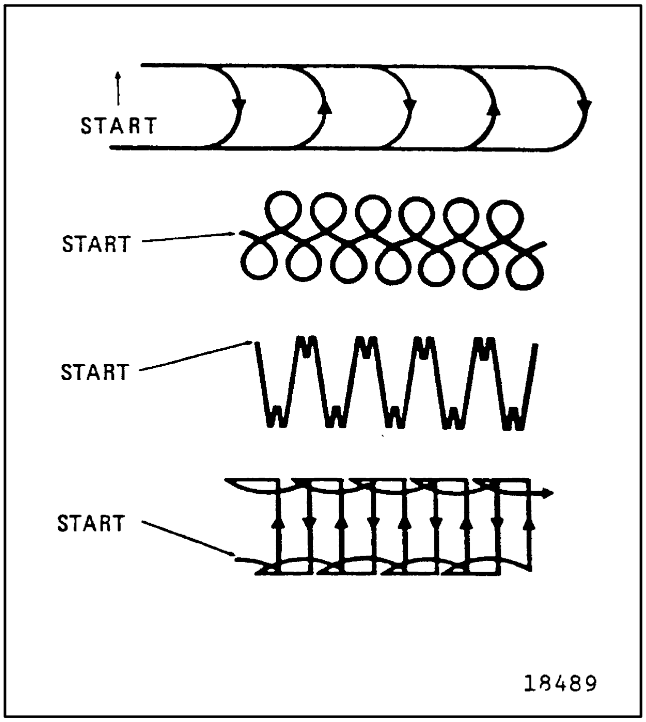


Figure 6–14. Weave Motion in Welding

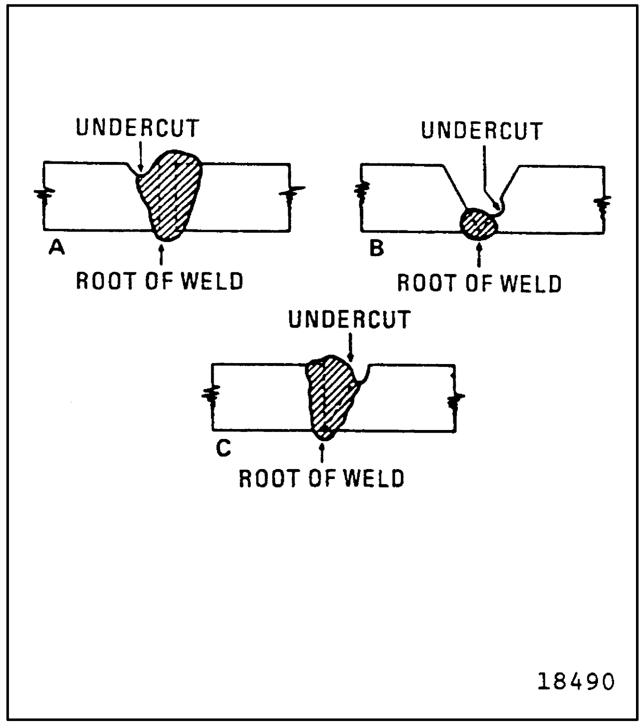


Figure 6–15. Undercutting in Butt Joint Welds

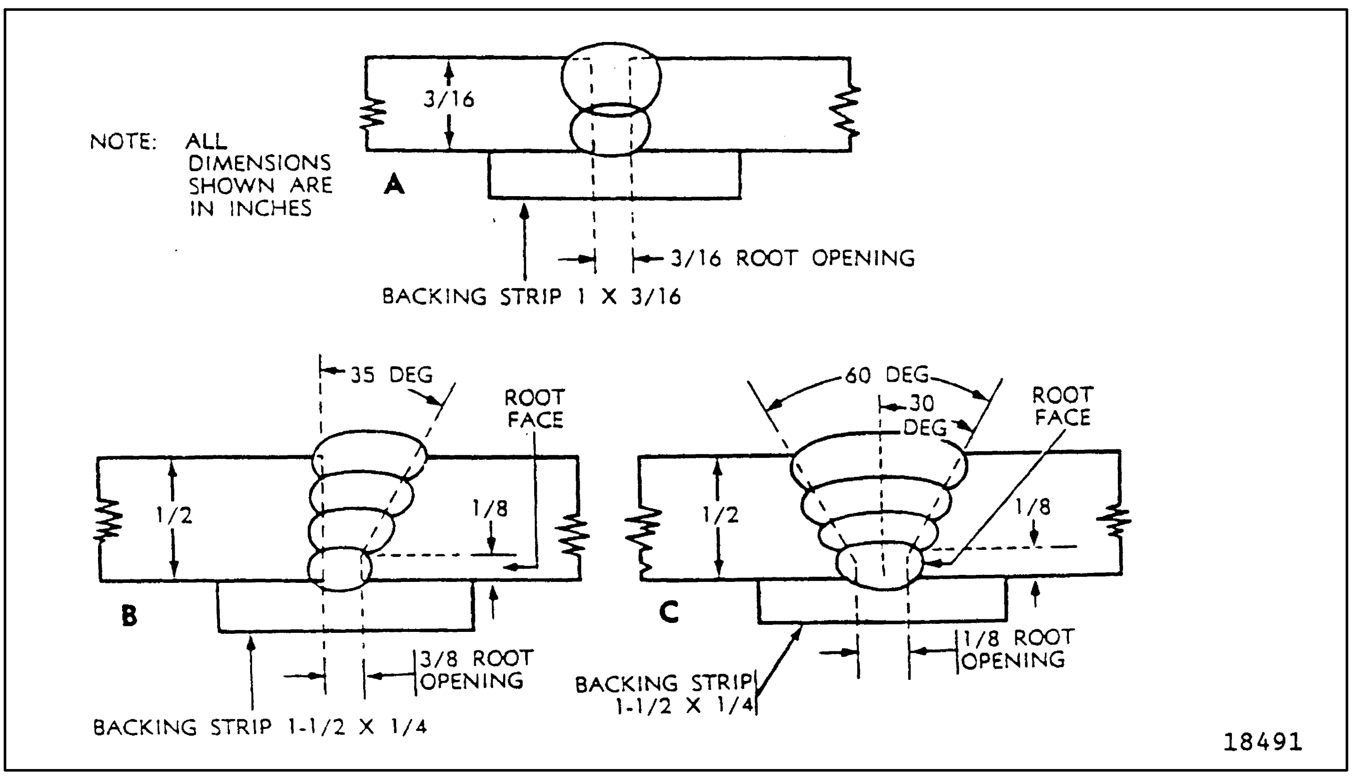


Figure 6–16. Butt Welds with Backing Strips

b. Lap Joints.

(1) In making lap joints, two overlapping plates are tack welded in place (figure 6–24) and then a fillet weld is deposited along the joint.

(2) The procedure for making this fillet weld is the same as that used in making fillet welds in tee joints except that the electrode should be held at an approximate 30 degree angle as shown in figure 6–25. The weaving motion is used and the pause at the edge of the top plate is sufficiently long to ensure good fusion and no undercut.

(3) In making lap joints on plates of different thicknesses the electrode is held so as to form an angle of 20 to 30 degrees from the vertical. Care must be taken not to overheat or undercut the edge of the thinner plate and the arc must be controlled to "wash- up" the molten metal to the edge of this plate.

6.1.8 Vertical Position Welding.

a. Vertical Welding.

(1) Welding on a vertical surface is more difficult than welding in a flat position since, due to the force of gravity, the molten metal tends to flow downward.

b. Weld Beads

(1) In welding in a vertical position, current settings should be less than those used in the flat position. Currents used for welding in an upward direction on a vertical plane are slightly lower than those used when welding downward.

(2) The proper angle between the electrode and the base metal is important to the deposit of a good bead in vertical welding. The welding electrode should be held at 90 degrees to the vertical, as shown at A, figure 6–26. When welding upward and weaving is necessary, the electrode should be oscillated, as shown at B, figure 6–26. When welding downward, the electrode should be inclined downward about 15 degrees from the horizontal with the arc pointing upward, as shown at C, figure 6–26. When welding downward, and a weave is required, the electrode should be oscillated as shown at D, figure 6–26.

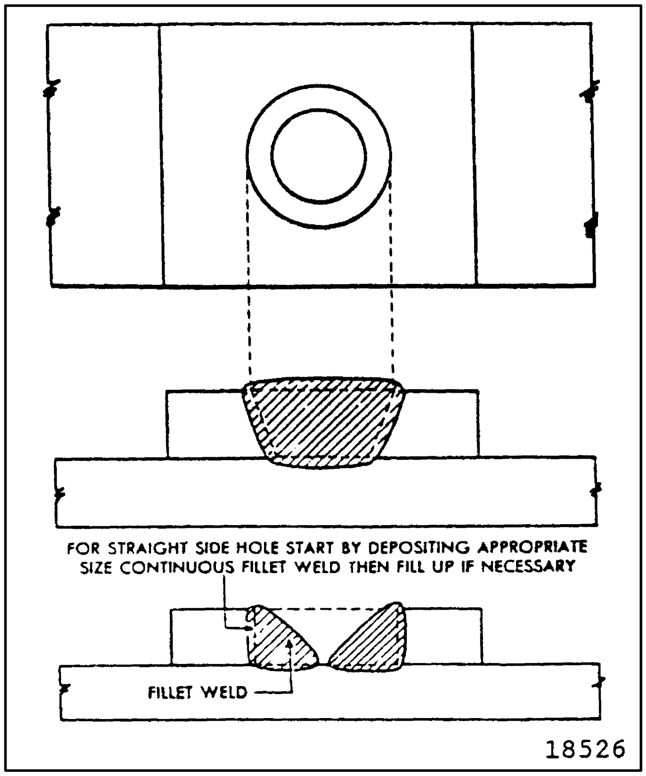


Figure 6–17. Plug Joint in Flat Position

(3) When depositing a weld bead in a horizontal direction on a vertical plate, the electrode should be held at right angles to the vertical plate and tilted about 15 degrees toward the direction of the welding, as shown in figure 6–27.

c. Butt Joints.

(1) Butt joints on plates in a vertical position are prepared for welding in the same way as those required for butt joints in flat positions (paragraph 6.1.6a), and backing strips may be used in the same manner described in paragraph 6.1.6b and illustrated in figure 6–16.

(2) Butt joints on beveled plates 1/4 inch in thickness can be made by using a triangular weave motion, as shown in figure 6–28.

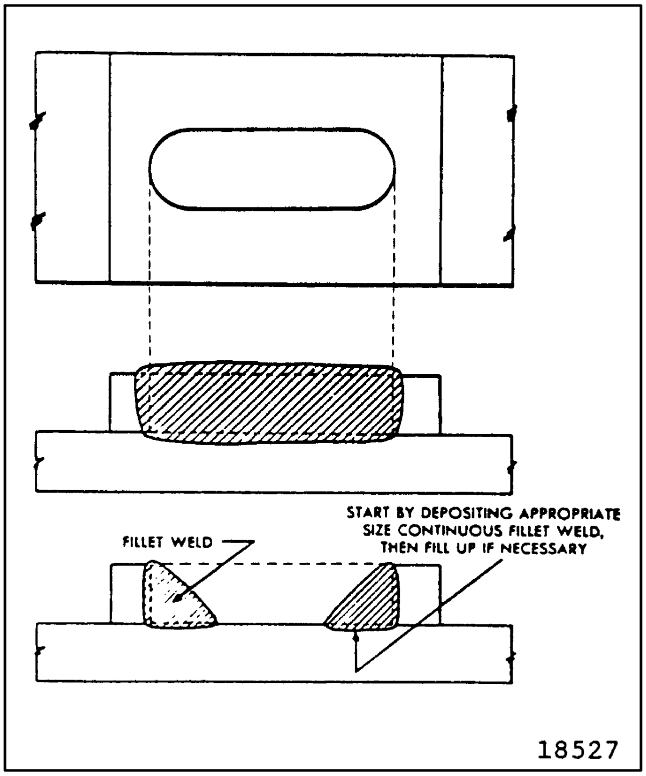


Figure 6-18. Slot Joint in Flat Position

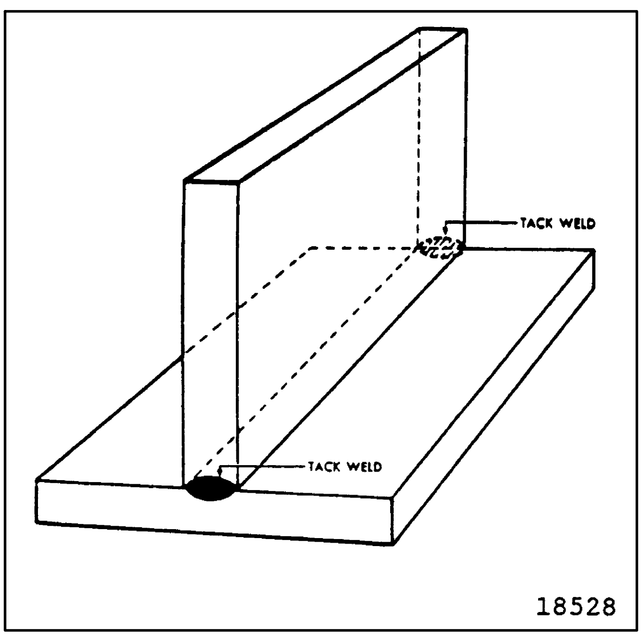


Figure 6-19. Tack Weld to Hold Tee Joint Elements in Place

(3) Welds on 1/2 inch thick plates, or heavier, should be made in several passes, as shown in figure 6-29. The first pass, or root weld, should be made with the electrode at 90 degrees to the vertical plate (A, figure 6-29) and subsequent passes made at 30 degrees to vertical plate (B and C, figure 6-29). All passes in the weld should be made with a semicircular weave or triangular motion.

(4) When welding butt joints in the horizontal direction on vertical plates, the metal is deposited in multi-pass beads, as shown in figure 6-29. The first pass is made at an angle of 90 degrees to the vertical plate and subsequent passes are made with the electrode held parallel to the beveled edge opposite the edge on which the bead is being deposited. The weaving motion should have a short pause at the edge of the weld.

d. Fillet Welds.

(1) In making fillet welds in lap joints the electrode should be held at 90 degrees to the plates or not more than 15 degrees above the horizontal for proper molten metal control (F, figure 6-30).

(2) In welding fillets in tee joints the electrode should be held at 90 degrees to the vertical position of the plate (A, figure 6-30) and approximately 1/2 of the distance, or 45 degrees, from each plate of the tee. In making the weaving motion care must be taken not to pass the electrode too close to either side of the tee so as not to strike an arc from the side of the electrode.

(3) In welding tee joints in the vertical position the weld should be started at the bottom and progress upward in a triangular weaving motion, as shown at A, figure 6-30. A slight pause in the weave at the points indicated will improve side wall penetration.

(a) If the weld metal should overheat and start to run, the electrode should be shifted away quickly from the crater, without breaking the arc (B, figure 6-30). This will permit the molten metal to solidify. The electrode should be returned immediately to the crater after the metal has ceased to run, in order to maintain the desired size of the weld.

(b) When more than one pass is necessary to make a fillet weld on a tee joint, either of two weaving motions (C or D, figure 6-30) may be used to lay succeeding beads on top of the root pass.

(4) To make fillet welds on lap joints in a vertical position, the electrode should be held in a 90 degree angle from the vertical position and at a 45 degree angle to the vertical plate (E, figure 6–30). The triangular weaving motion should be used and the pause at the end of the weave on plate G should be slightly longer than that at the edge of plate H. Care should be taken not to undercut either plate or to allow the molten metal to overlap at the edges of the weave.

6.1.9 Overhead Position Welding.

a. Overhead Welding. The overhead position is the most difficult in welding and a well maintained arc is necessary in order to retain complete control of the molten metal. As in vertical welding, the force of gravity tends to cause the metal to sag on the plate or drop away from the joint. If the arc is too long the difficulty of transferring the metal from the electrode to the metal is increased and large globules of metal will drop from the electrode. If the arc is too short the electrode will periodically freeze to the plate (see paragraph 6.1.3a(4)). This action can be prevented by intermittently shortening and lengthening the arc slightly during the welding procedure. Care should be taken never to carry too large a pool of molten metal in the weld.

b. Weld Beads.

(1) For welding beads in the overhead position, the electrode should be held at 90 degrees to the base metal (A, figure 6–31) or tilted approximately 15 degrees in the direction of the weld, as shown in B, figure 6–31, if it will provide a better view of the arc and crater.

(2) Weave beads can be accomplished by using the motion illustrated at C, figure 6–31. A rather rapid motion at the end of each semicircular weave is necessary in order to control the molten metal deposit. Excessive weaving will cause overheating and formation of large molten metal pools, which will be hard to control.

c. Butt Joints.

(1) Plates for overhead position welding should be prepared the same as those required for flat positioning (paragraph 6.1.6) and the weld is most satisfactory if backing strips are used. If the plates are beveled with a feather edge and no backing strip is used, the weld will tend to burn through unless extreme care is taken by the operator.

(2) For overhead butt welding, bead rather than weaving welds are preferred. Each bead should be cleaned and rough areas of the weld chipped before subsequent passes are made.

(3) The positions of the electrode in relation to the plates are shown in figure 6–32 for depositing weld beads on 1/4 to 1/2 inch material. The first pass is deposited as illustrated in A, figure 6–32 and subsequent passes are shown in B and C, figure 6–32.

(4) The electrodes should not be too large in diameter as this will prevent holding the correct arc to insure good penetration at the root of the joint. Avoid excessive current. This would create a very fluid puddle which is difficult to control.

d. Fillet Welds.

(1) In making fillet welds in either tee or lap joints in the overhead position, weaving of the electrode is not recommended. The electrode should be held at approximately 30 degrees to the vertical plate and moved uniformly in the direction of the welding with a 15 degree tilt so the operator can observe the condition of the molten metal as it is deposited (B, and C, figure 6–33). The arc motion should be controlled to secure good penetration to the root of the weld and good fusion with the side walls of the plates. If the molten metal becomes too fluid and tends to sag, the electrode should be quickly whipped away from the crater and ahead of the weld to lengthen the arc and allow the metal to solidify. The electrode should then be returned to the crater and welding continued.

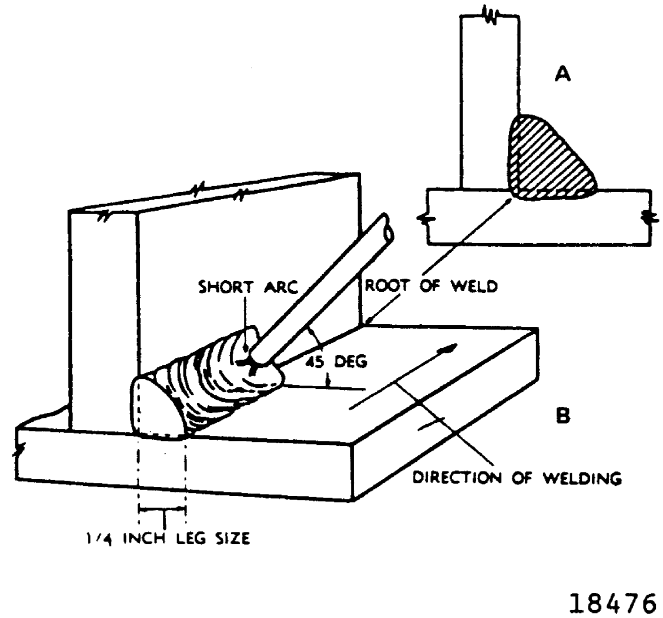


Figure 6-20. Position of Electrode and Fusion Area of Fillet Weld on the Joint

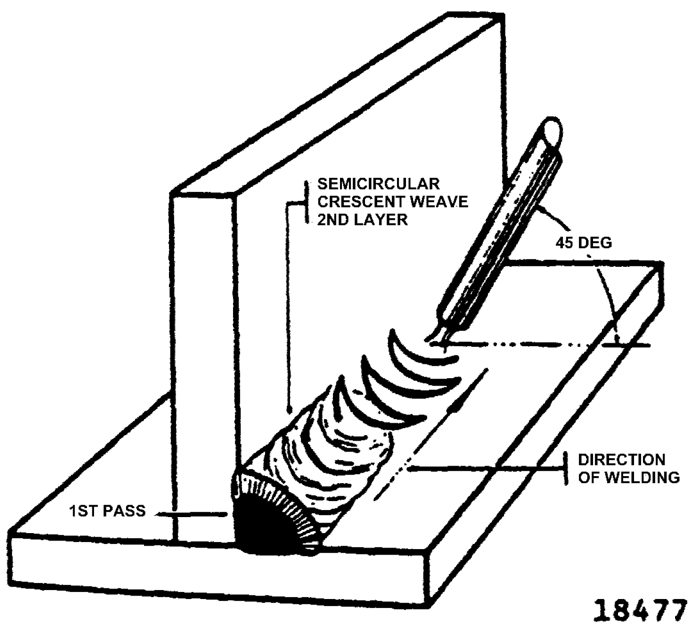


Figure 6-21. Weave Motion for Multipass Fillet Weld

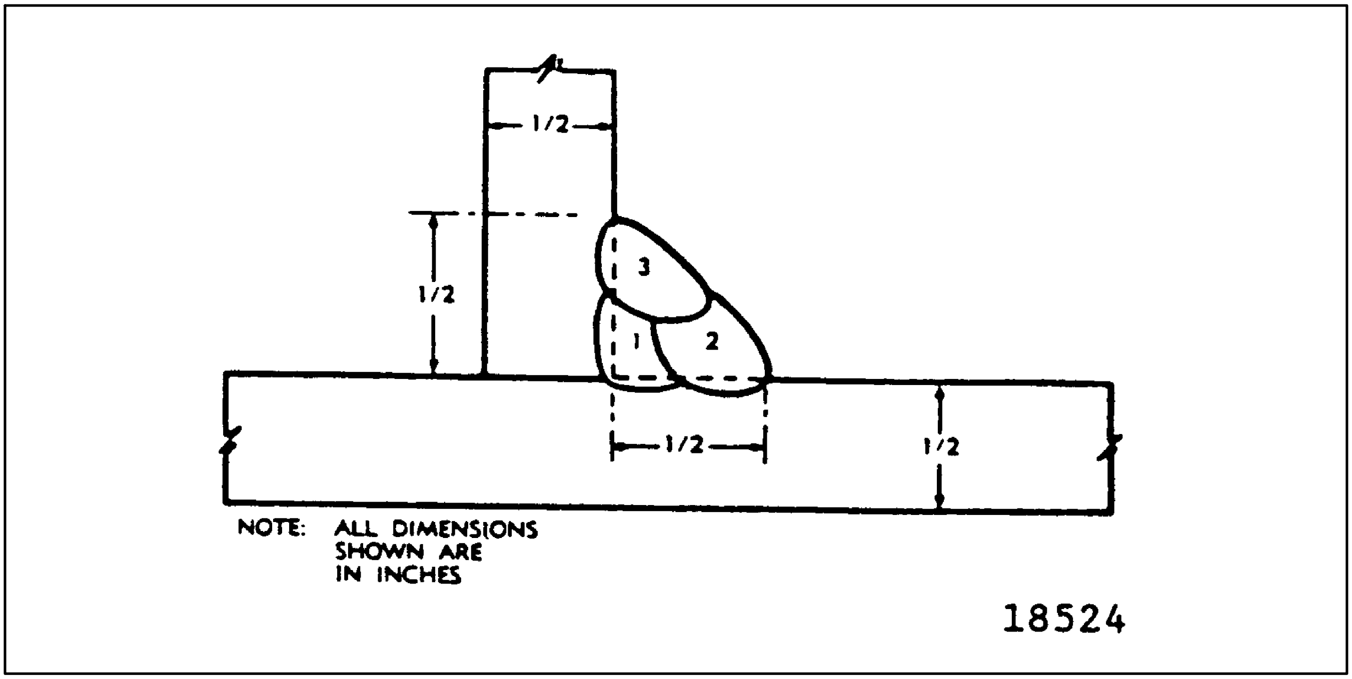


Figure 6-22. Fillet Welded Tee Joint on Heavy Plate

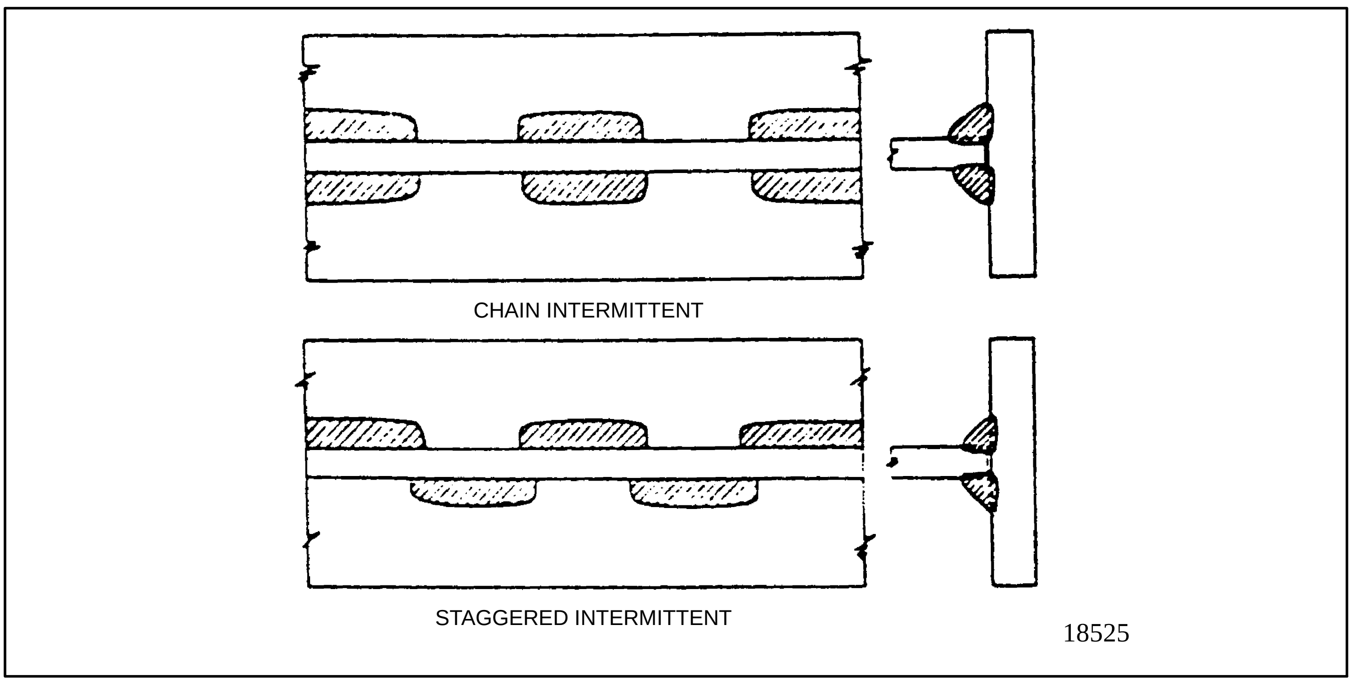


Figure 6-23. Intermittent Fillet Welds

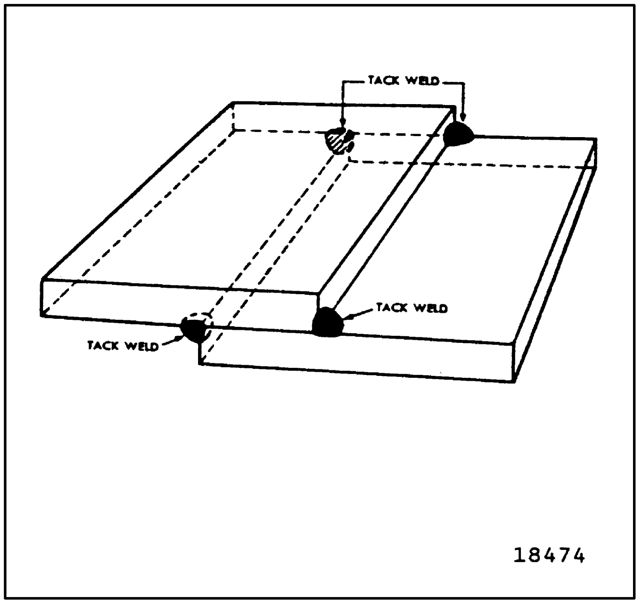


Figure 6-24. Tack Welding a Lap Joint

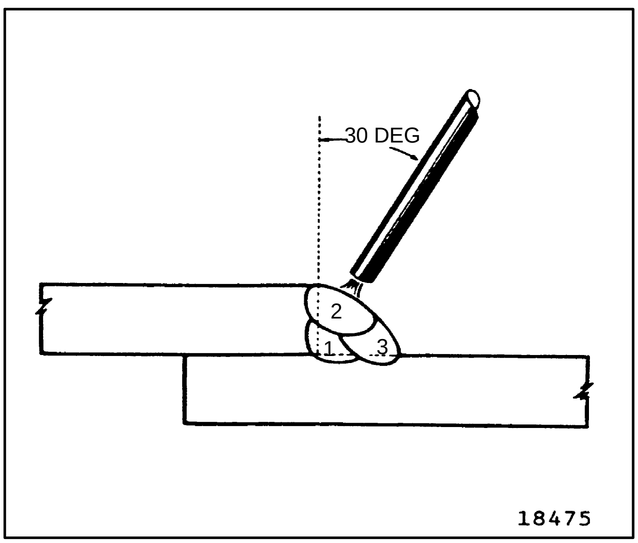


Figure 6-25. Position of Electrode on Lap Joint

(2) Fillet welds for either tee or lap joints on heavy plate in overhead positions may require several passes to make a secure joint. The order in which these beads are deposited is shown in A, figure 6-33. The first, or root pass is a string bead with good penetration and fusion to the root and side walls of the plates. Second, third, and fourth passes are then applied and although a weaving motion is not used to apply these beads the electrode is moved in a slight circular motion, as shown in C, figure 6-33. This motion of the electrode permits greater control and better distribution of the metal being deposited. All slag and oxides must be removed from the surface of the weld between each successive pass.

6.2 HEAT EFFECTS IN ELECTRIC ARC WELDING.

6.2.1 General.

a. The heat affected zone in welding operations is that portion of the base metal which is changed metallurgically by the welding heat. This heat affected zone consists of three sections: the very hot section next to the molten filler metal, the annealed section next to the over-heated base metal and the section adjacent to the cold base metal.

b. The rate at which heat is applied to the plates is greater in arc welding than in oxyacetylene welding; this causes a higher concentration of heat at a particular point, and therefore, steeper heat climb at that particular point but less metal affected by the heat. In bare metal arc welding, the heat affected zone is narrowest; it increases with heavy coated electrodes. Stainless steel electrodes produce a smaller heat affected zone than the heavy coated electrodes.

6.2.2 Factors Affecting the Heat Affected Zone.

a. In general, the extent of the heat affected zone will increase with the amount of welding energy used in arc welding. This energy is a function of the voltage and amperage settings.

b. Greater penetration for arc welds is not necessarily obtained with an increase in the heat affected zone because this increase is in width rather than in depth. With the exception of cored and stainless steel arc welds, the smaller the heat affected zone, the more rapid is the removal of heat from this area by the surrounding parent metal.

c. In arc welding, the extent of the heat affected zone is increased under the conditions listed below:

(1) When, with a constant current, the welding speed is slowed.

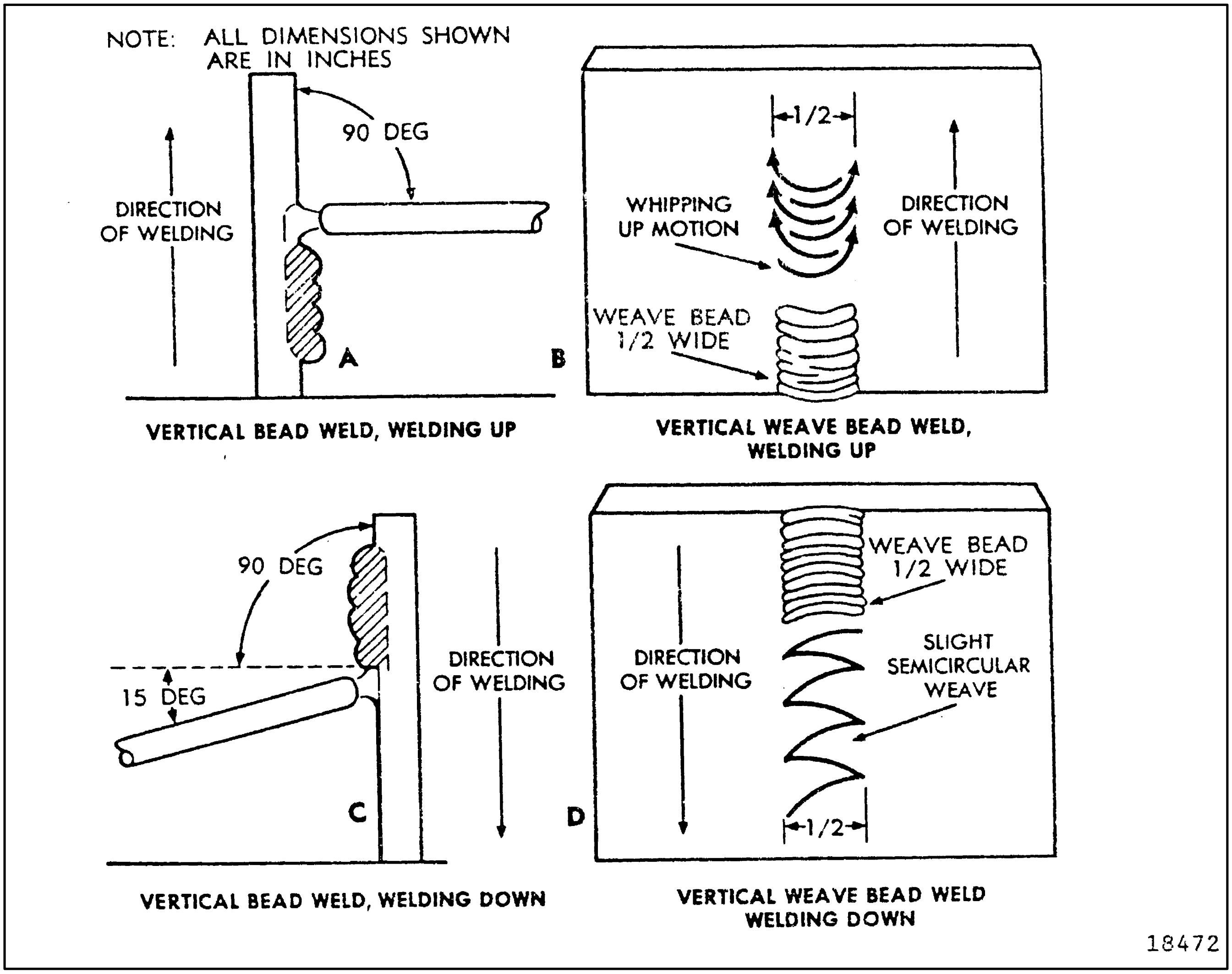


Figure 6–26. Bead Welding in a Vertical Position

(2) When, with a constant welding speed, the current is increased.

(3) When lighter sections of plate are welded.

(4) When preheating is necessary.

6.2.3 Hardness in Arc Welding.

a. Arc welding produces greater hardness in the heat affected zone than oxyacetylene welding for the same type of welding operation, and the hardened zone is more concentrated. In general the greater the hardness produced in arc welds, the more likely is the weld to crack when the molten metal solidifies.

b. Arc welds on plate containing 0.35 percent carbon or higher show a greater rate of increase in hardness than in steels containing a lesser amount of carbon. In alloy steels, certain elements are added to increase the strength, but these also increase the hardness produced by the carbon. Readily weldable grades of plate are those with a low carbon content since the welding process on these will not induce excessive hardness.

c. In plain carbon steels having 0.25 percent carbon or less, welds made by either arc or gas welding do not cause any noticeable degree of change in hardness, ductility, or tensile strength.

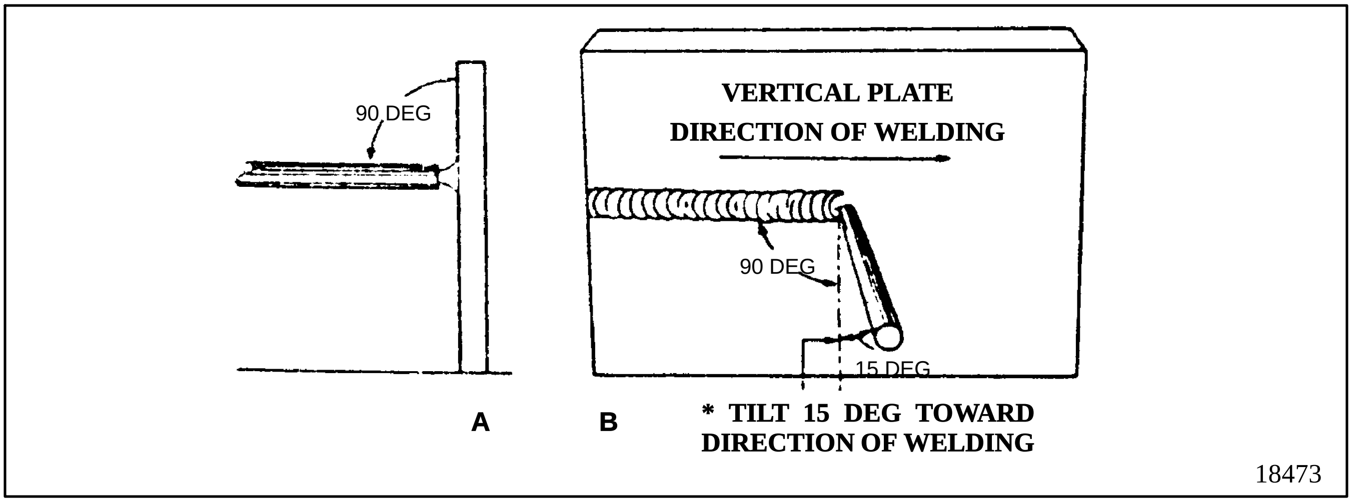


Figure 6-27. Vertical Position Welding with Bead in Horizontal Position

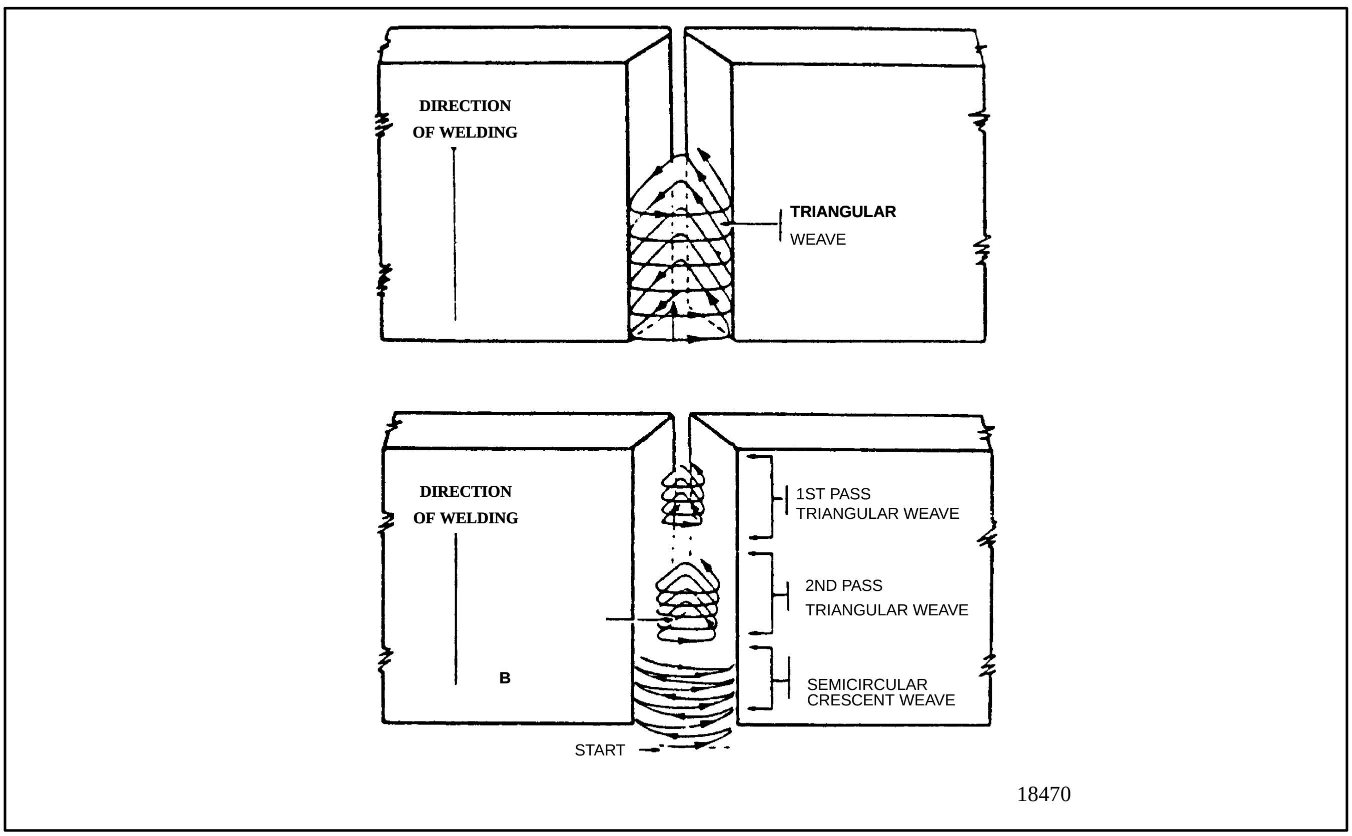


Figure 6-28. Welding Butt Joint in Vertical Position

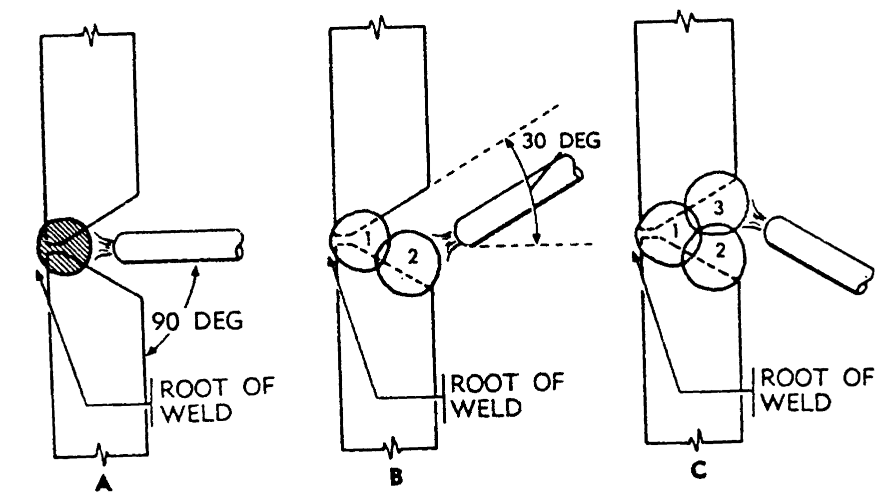


Figure 6-29. Welding Butt Joint on Vertical Plates

6.2.4 Electric Arc Welding of Ferrous Metals.

a. Low Carbon Steels.

(1) General.

(a) The low carbon steels include those with a carbon content up to 0.30 percent (figure 6-34). These low carbon steels do not harden appreciably when welded and therefore do not require preheating or postheating except in special cases, such as when heavy sections are to be welded.

b. Metal-Arc Welding.

(1) In metal-arc welding the bare, thin coated or heavy coated shielded arc types of electrodes may be used. These electrodes are of low carbon type (0.10 to 0.14 percent).

(2) Low carbon sheet or plate materials that have been exposed to low temperatures should be preheated slightly (to room temperature) before welding.

(3) In welding sheet metal up to 1/8 inch in thickness, the plain square butt joint type of edge preparation may be used. When long seams are to be welded in this material, the edges should be spaced to allow for shrinkage because the deposited metal tends to pull the plates together. This shrinkage is less severe in arc welding than in gas welding and spacing of approximately 1/8 inch per foot of seam will suffice.

(4) The backstep or skip welding technique should be used for short seams that are fixed in place, in order to prevent warpage or distortion and minimize residual stresses (figure 6-35).

(5) Heavy plates should be beveled to provide an included angle up to 60 degrees, depending on the thickness. The parts should be tack welded in place at short intervals along the seam and the first or root bead should be made with an electrode small enough in diameter to obtain good penetration and fusion at the base of the joint. A 1/8 or 5/32 inch electrode is suitable for this purpose. This first bead should be thoroughly cleaned by chipping and wire brushing before additional layers of weld metal are deposited. The additional passes of filler metal should be made with a 5/32 or 3/16 inch electrode. These passes should be made with a weaving motion for plates in flat, horizontal, or vertical positions. For overhead welding, best results are obtained by using string beads throughout the weld.

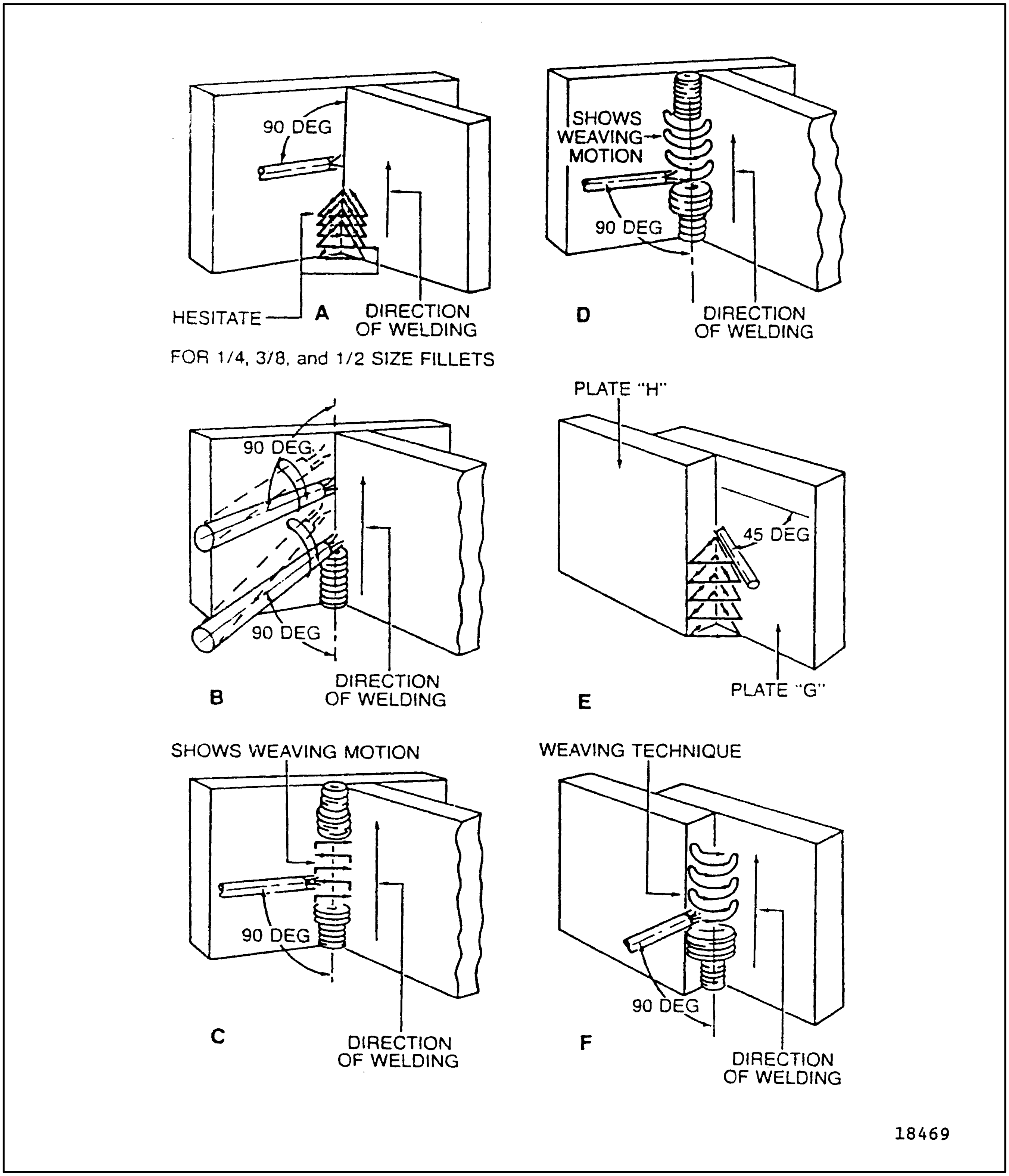


Figure 6-30. Vertical Welds in Vertical Position

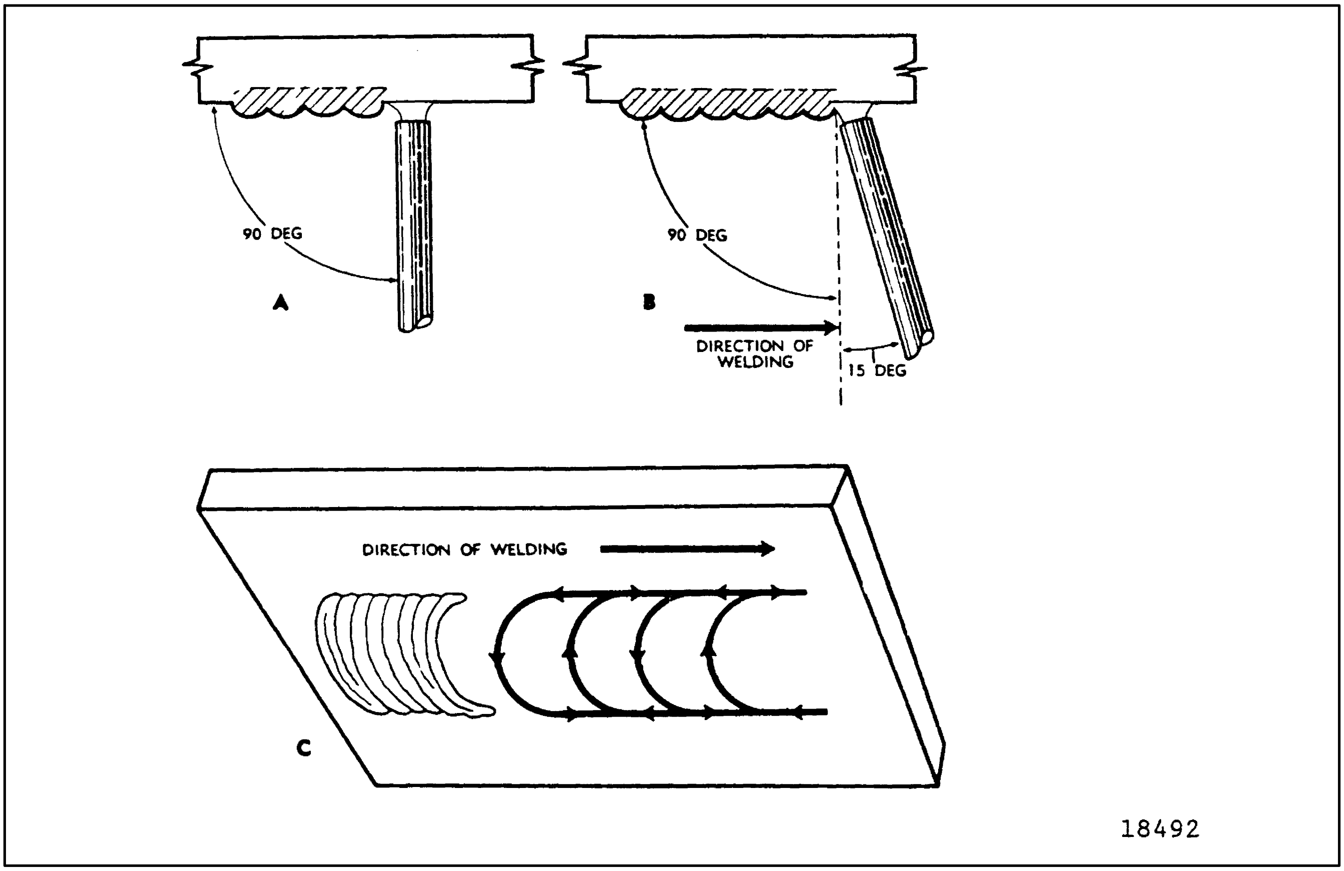


Figure 6–31. Position of Electrode and Weave Motion in Overhead Position

(6) In welding heavy sections that have been beveled from both sides, the weave beads should be deposited alternately on one side and then the other to reduce the amount of distortion in the welded structure. Each bead should be cleaned thoroughly to remove all scale, oxides, and slag before additional metal is deposited. The motion of the electrode should be controlled so as to make the bead uniform in thickness and to prevent undercutting and overlap at the edges of the weld. All slag and oxides should be removed from the surface of the completed weld to prevent rusting.

6.2.5 Medium Carbon Steels.

a. General.

(1) Medium carbon steels include those that contain from 0.30 to 0.55 percent carbon. These steels are usually preheated to between 300_ and 500_F (149_ and 260_C) before welding. Electrodes of the low carbon, heavy coated, straight or reverse polarity type, similar to those used for metal arc welding of low carbon steels, are satisfactory for welding steels in this group. The preheating temperatures will vary, depending on the thickness of the plates and their carbon content. After welding, the entire joint should be heated to between 1,000_ and l,200_F (538_ and 649_C) and slowly cooled to relieve stresses in the base metal adjacent to the weld.

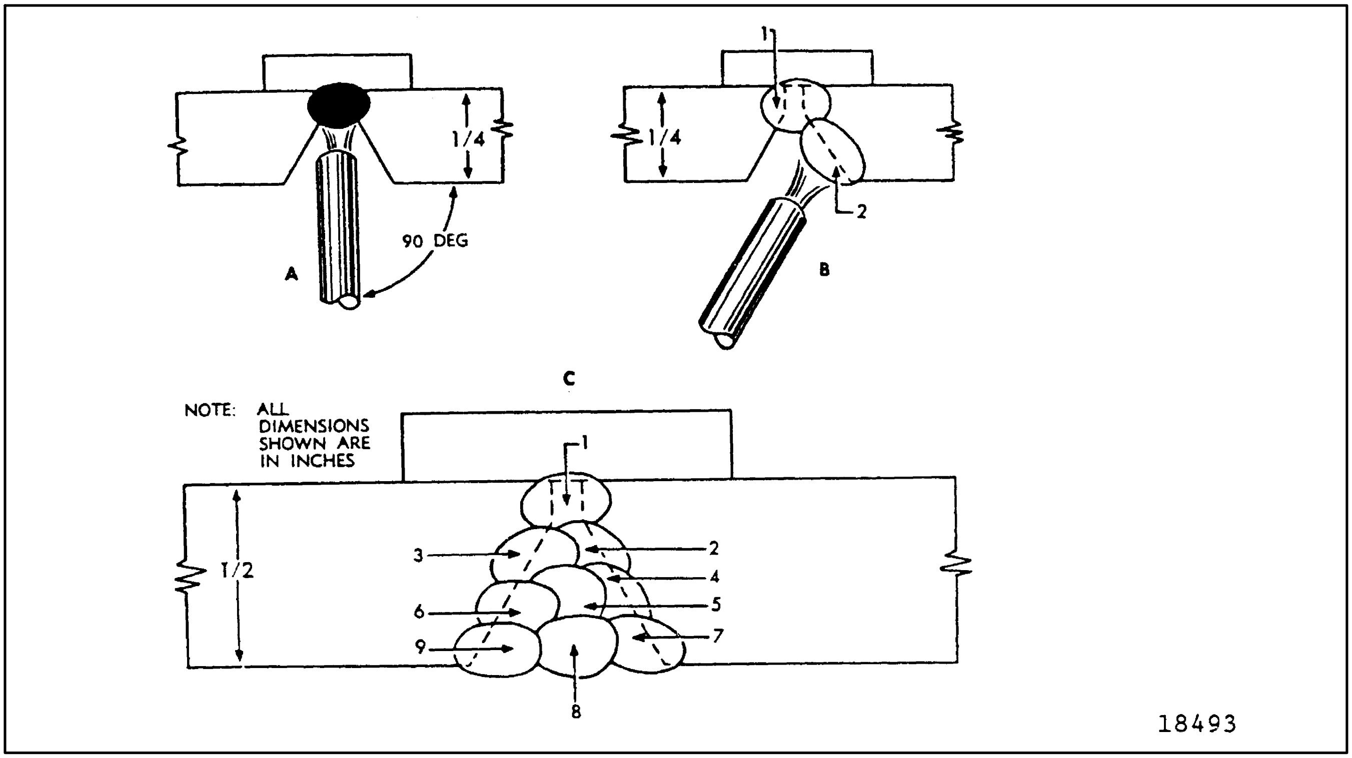


Figure 6-32. Multipass Butt Joint in Overhead Position

b. Welding Techniques.

(1) The plates should be prepared for welding in a manner similar to that used for low carbon steels. When welding with low carbon steel electrodes, the welding heat should be carefully controlled to avoid overheating of the weld metal and excessive penetration into the side walls of the joint. This control is accomplished by directing the electrode more toward the previously deposited filler metal adjacent to the side walls than toward the side walls directly. By using this procedure, the weld metal is caused to wash up against the side of the joint and fuse with it without deep or excessive penetration.

(2) High welding heats will cause large areas of the base metal in the fusion zone adjacent to the welds to become hard and brittle. The area of these hard zones in the base metal can be kept at a minimum by making the weld with a series of small string or weave beads, which will limit the heat input. Each bead or layer of weld metal will refine the grain in the weld immediately beneath it and will anneal and lessen the hardness produced in the base metal by the previous bead.

(3) When possible, the finished joint should be heat treated after welding. Stress relieving is normally used when joining mild steel; high carbon alloys should be annealed.

(4) In welding medium carbon steels with stainless steel electrodes, the metal should be deposited in string beads to prevent cracking of the weld metal in the fusion zone. When depositing weld metal in the upper layers of welds made on heavy sections, the weaving motion of the electrode should under no circumstances exceed three electrode diameters.

(5) Each successive bead of weld should be chipped, brushed, and cleaned prior to the laying of another bead.

6.2.6 High Carbon Steels.

a. General.

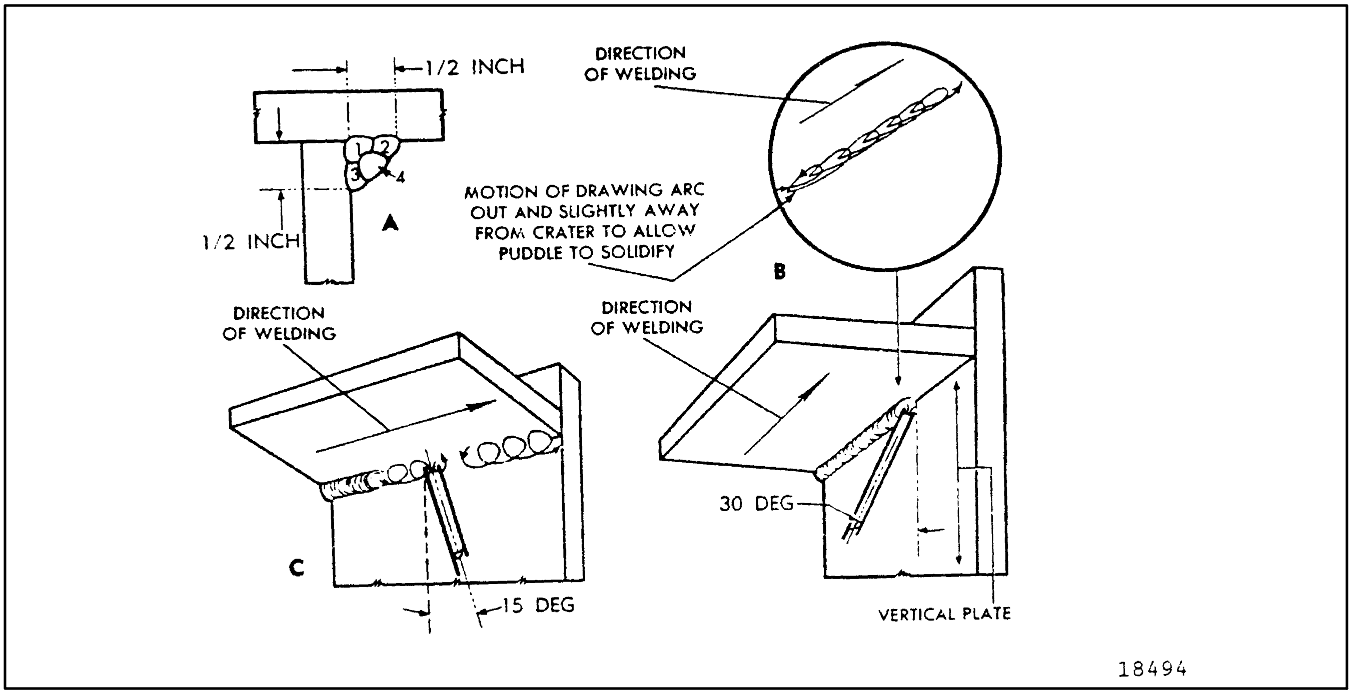


Figure 6–33. Fillet Welding in Overhead Position

(1) High carbon steels include those having a carbon content exceeding 0.55 percent. Because of the high carbon content and the heat treatment usually given to these steels, their basic properties are to some degree impaired by arc welding. Preheating 500_ to 800_F (260_ to 427_C) before welding and stress relieving by heating from 1,200_ to 1,450_F (649_ to 788_C) with slow cooling should be used to avoid hardness and brittleness in the fusion zone. Either mild steel or stainless steel electrodes can be used with these steels.

b. Welding Technique.

(1) The welding heat should be adjusted to provide good fusion at the side walls and root of the joint without excessive penetration. Control of the welding heat can be accomplished by depositing the weld metal in small string beads. Excessive puddling of the metal should be avoided, because this will cause carbon to be picked up from the base metal which, in turn, will make the weld metal hard and brittle. Fusion between the filler metal and the side walls should be confined to a narrow zone. Use the surface fusion procedure prescribed for medium carbon steels (paragraph 6.2.5b(4)).

(2) The same procedure for edge preparation, cleaning of the welds, and sequence of welding beads as prescribed for low and medium carbon steels applies to high carbon steels.

(3) Small high carbon steel parts are sometimes repaired by building up worn surfaces. When this is done, the piece should be annealed or softened by heating to a red heat and cooling slowly. Then the piece should be welded or built up with medium carbon or high strength electrodes and heat treated after welding to restore its original properties.

6.2.7 Tool Steels.

a. General.

(1) Steels in this group have a carbon content ranging from 0.83 to 1.55 percent. They are rarely welded by arc welding, because of the excessive hardness produced in the fusion zone of the base metal. If arc welding must be done, either mild steel or stainless steel electrodes can be used.

b. Welding Technique.

(1) If the parts to be welded are small, they should be annealed or softened before welding. The edges should then be preheated up to 1,000_F (538_C) depending on the carbon content and thickness of the plate, and the welding should be done with either a mild steel or high strength electrode.

(2) High carbon electrodes should not be used for welding tool steels. The carbon pickup up from the base metal by the filler metal will cause the weld to become glass hard, whereas the mild steel electrode weld metal can absorb additional carbon without becoming excessively hard. The welded part should then be heat treated to restore its original properties.

(3) In welding with stainless steel electrodes, the edges of the plates should be preheated to prevent the formation of hard zones in the base metal. The weld metal should be deposited in small string beads to keep the heat input down to a minimum. In general, the application procedure is the same as that required for medium and high carbon steels.

6.2.7.1 High Hardness Alloy Steels. Many varieties of alloy steels have been developed to obtain high strength, high hardness, corrosion resistance, and other special properties. Most of these steels depend on a special heat treatment process in order to develop the desired characteristic in the finished state. Many of these steels can be welded with a heavy coated electrode of the shielded arc type whose composition is similar to that of the base metal. Low carbon electrodes can also be used with some steels and stainless steel electrodes are effective where preheating is not practicable or is undesirable. Heat treated steels should be preheated, if possible, in order to minimize the formation of hard zones or layers in the base metal adjacent to the weld. The molten metal should not be overheated and for this reason, the welding heat should be controlled by depositing the weld metal in narrow string beads. In many cases, the procedure outlined for medium carbon steels (paragraph 6.2.5) and high carbon steels (paragraph 6.2.6) including the principles of surface fusion, can be used in the welding of alloy steels.

6.2.8 High Yield Strength, Low Alloy Structural Steels.

a. General.

(1) High yield strength, low alloy structural steels are special steels that are tempered to obtain extreme toughness and durability. The special alloys and general makeup of these steels require special treatment to obtain satisfactory weldments.

b. Welding Technique.

Reliable welding of high yield strength, low alloy structural steels can be performed by using the following guidelines:

(1) Correct Electrodes.

(a) Hydrogen is the number one enemy of sound welds in alloy steels, therefore, use only LOW HYDROGEN electrodes to prevent underbead cracking. Underbead cracking is caused by hydrogen picked up in the electrode coating, released into the arc and absorbed by the molten metal.

(2) Moisture control of electrodes.

(a) If the electrodes are in an airtight container, immediately upon opening the container place the electrodes in a ventilated holding oven set at 250_ to 300_ F (121_ to 149_ C). In the event that the electrodes are not in an airtight container, put them in a ventilated baking oven and bake for 1/4 to 1 hour at 800_ F (427_C). While they are still warm, place electrodes in the holding oven until used. Electrodes must be kept dry to eliminate absorption of hydrogen.

c. Low Hydrogen Electrode Selection.

(1) Electrodes are identified by classification numbers which are always marked on the electrode containers. For low hydrogen coatings the last two numbers of the classification should be 15, 16, or 18. Electrodes of 5/32 and 1/8 inch in diameter are the most commonly used since they are more adaptable to all types of welding on this type of steel. Table 6–4 is a list of electrodes used to weld high yield strength, low alloy steels.

d. Selecting Wire–Flux and Wire–Gas Combinations.

(1) Wire electrodes for submerged arc and gas–shielded arc welding are not classified according to strength. Welding wire and wire–flux combinations used for steels to be stress relieved should contain no more than 0.05 percent vanadium. Weld metal with more than 0.05 percent vanadium may become brittle if stress relieved. When using either the submerged arc or gas metal–arc welding processes to weld high yield strength, low alloy structural steels to lower strength steels, the wire–flux and wire–gas combination should be the same as that recommended for the lower strength steels.

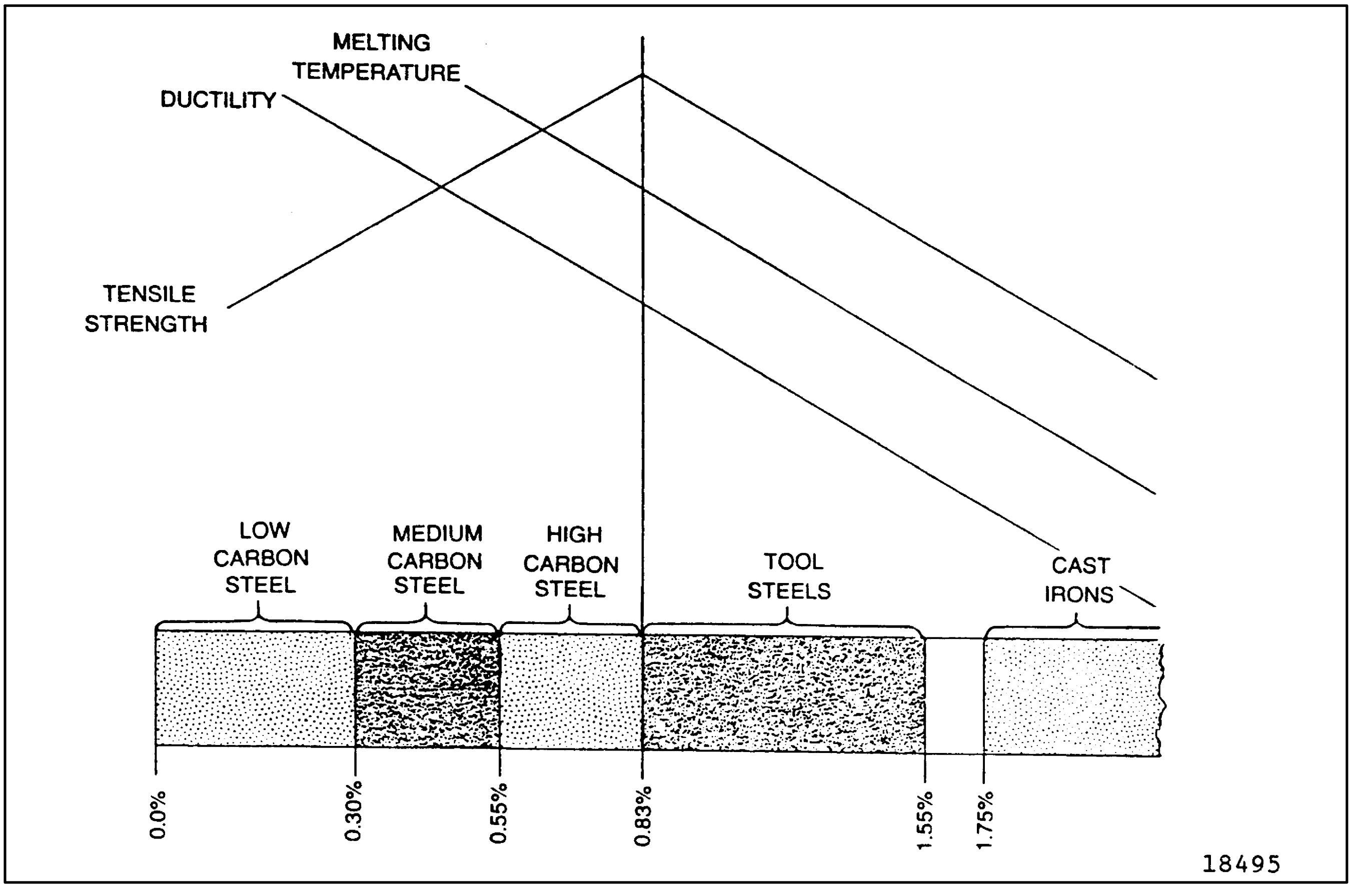


Figure 6-34. How Steel Qualities Change as Carbon is Added

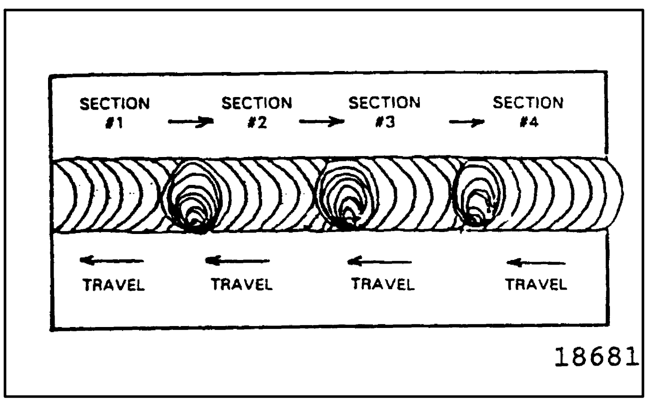


Figure 6-35. Backstep Method

e. Preheating.

(1) For welding plates under 1-inch thick, preheating above 50_ F (10_ C) is not required except to remove surface moisture from the base metal. Table 6-5 contains suggested preheating temperatures.

f. Welding Process.

For satisfactory welds use good welding practices, as defined in this section, along with the following procedures:

(1) Use a straight stringer bead whenever possible.

(2) Restrict weave to partial weave pattern. Best results are obtained by a slight circular motion of the electrode with the weave area never exceeding two electrode diameters.

(3) Never use a full weave pattern.

(4) Skip weld as practical.

(5) Peening of the weld is sometimes recommended to relieve stresses while cooling larger pieces.

(6) Fillet welds should be smooth and correctly contoured. Avoid toe cracks and undercutting. Electrodes used for fillet welds should be lower strength than those used for butt welding. Air–hammer peening of fillet welds can help to prevent cracks, especially if the welds are to be stress relieved. A soft steel wire pedestal can help to absorb shrinkage forces. Butter welding in the toe area before actual fillet welding strengthens the area where a toe crack may start. A bead is laid in the toe area, then ground off prior to the actual fillet welding. This butter weld bead must be located so that the toe passes of the fillet will be laid directly over it during actual fillet welding. Because of the additional material involved in fillet welding the cooling rate is increased and heat inputs may be extended about 25 percent.

6.2.9 Cast Iron.

a. General.

(1) Gray cast iron has low ductility and therefore will not expand or stretch to any considerable extent before breaking or cracking. Because of this characteristic, preheating is necessary when cast iron is welded by the oxyacetylene welding process. It can, however, be welded with the metal–arc process without preheating if the welding heat is carefully controlled. This can be accomplished by welding only short lengths of the joint at a time and allowing these sections to cool. By this procedure, the heat of welding is confined to a small area and the danger of cracking the casting is eliminated. Large castings with complicated sections, such as motor blocks, can be welded without dismantling or preheating. Special electrodes designed for this purpose are usually desirable.

b. Edge Preparation.

(1) The edges of the joint should be chipped out or ground to form a 60 degree angle or bevel. The V should extend to approximately 1/8 inch from the bottom of the crack. A small hole should be drilled at each end of the crack to prevent it from spreading. All grease, dirt, and other foreign substances should be removed by washing with a suitable cleaning material.

c. Welding Technique.

(1) Cast iron can be welded with a coated steel electrode, but this method should be used as an emergency measure only. When using a steel electrode, the contraction of the steel weld metal, the carbon picked up from the cast iron by the weld metal, and the hardness of the weld metal caused by rapid cooling must be considered. Steel shrinks more than cast iron when cooled from a molten to a solid state and, when a steel electrode is used, this uneven shrinkage will cause strains at the joint after welding. When a large quantity of filler metal is applied to the joint, the cast iron may crack just back of the line of fusion unless preventive steps are taken. To overcome these difficulties, the prepared joint should be welded by depositing the weld metal in short string beads, 3/4 to 1 inch long, made intermittently and, in some cases, by the backstep and skip procedure. To avoid hard spots, the arc should be struck in the V and not on the surface of the base metal. Each short length of weld metal applied to the joint should be lightly peened while hot with a small ball peen hammer and allowed to cool before additional weld metal is applied. The peening action forges the metal and relieves the cooling strains.

(2) The electrodes used should be 1/8 inch in diameter so as to prevent excessive welding heat, the welding should be done with reverse polarity, and the weaving of the electrode should be held to a minimum. Each weld metal deposit should be thoroughly cleaned before additional metal is added.

(3) Cast iron electrodes are used where subsequent machining of the welded joint is required. Stainless steel electrodes are used when machining of the weld is not required. The procedure for making welds with these electrodes is the same as that outlined for welding with mild steel electrodes. Stainless steel electrodes provide excellent fusion between the filler and base metals but great care must be taken to avoid cracking in the weld, because stainless steel expands and contracts approximately 50 percent more than mild steel in equal changes of temperature.

Table 6–4. Electrode Numbers

E8015[1]	E9015[2]	E10015	E11015	E12015
E8016[2]	E9016	E10016	E11016	E12016
E8018	E9018	E10018	E11018	E12018

1 The E indicates electrode; the first two or three digits indicate tensile strength; the last two digits indicate covering; 15, 16 and 18 all indicate a low hydrogen covering.

2. Low hydrogen electrodes E80 and E90 are recommended for fillet welds since they are more ductile than the higher strength electrodes which are desirable for butt welds.

Table 6–5. Suggested Preheat Temperature[1]

Plate thickness (inch)	Shielded metal–arc (manual arc) welding [2]	Gas metal–arc welding [3]	Submerged arc welding	
			Carbon steel or alloy wire, neutral flux [4]	Carbon steel wire, alloy flux [5]
Up to 1/2, inclusive	50_F (10_C)	50_F (10_C)	50_F (10_C)	50_F (10_C)
Over 1/2 to 1, inclusive	50_F (10_C)	50_F (10_C)	50_F (10_C)	200_F 93_C
Over 1 to 2, inclusive	150_F (66_C)	150_F (66_C)	200_F (93_C)	300_F (149_C)
Over 2	200_F (93_C)	200_F (93_C)	300_F (149_C)	400_F (204_C)

1 Preheated temperatures above the minimum shown may be necessary for highly restrained welds. However, preheat or interpass temperatures should never exceed 400_F (204_C) for thicknesses up to and including 1 1/2 inches, or 450_F (232_C) for thicknesses over 1 1/2 inches.

2 Electrode E11018 is normal for this type steel. However, E12015, 16 or 18 may be necessary for thin sections, depending on design stress. Lower strength low hydrogen electrodes E100XX ;may also be used.

3 Example: A–632 wire (Airco) and argon with 1 percent oxygen.

4 Example: Oxweld 100 wire (Linde) and 709–5 flux.

5 Example: L61 wire (Lincoln) and A0905 X A10 flux.

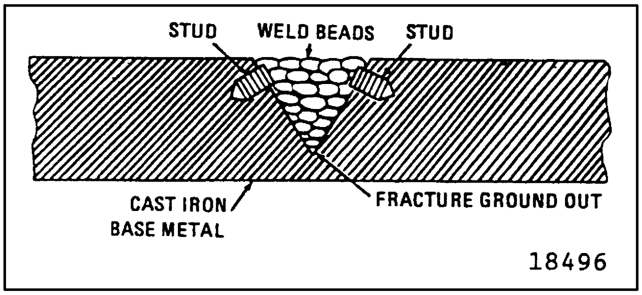


Figure 6–36. Studding Method for Cast Iron Repair

d. Studding.

(1) Cracks in large castings are sometimes repaired by "studding" (figure 6–36). In this process, the fracture is removed by grinding a V groove, holes are drilled and tapped at an angle on each side of the groove, and studs are screwed into these holes for a distance equal to the diameter of the studs, with the upper ends projecting approximately 1/4 inch above the cast iron surface. The studs should be seal welded in place by one or two beads around each stud and then tied together by weld metal beads. Welds should be made in short lengths and each length peened while hot to prevent high stresses or cracking upon cooling. Each bead should be allowed to cool and be thoroughly cleaned before additional metal is deposited. If the studding method cannot be applied, the edges of the joint should be chipped out or machined with a round–nosed tool to form a U groove into which the weld metal should be deposited.

e. Metal–Arc Brazing of Cast Iron.

(1) Cast iron can be brazed with heavy coated, reverse polarity bronze electrodes. The joints made by this method should be prepared in a manner similar to that used for oxyacetylene brazing of cast iron. The strength of the joint depends on the quality of the bond between the filler metal and the cast iron base metal.

f. Carbon–Arc Welding of Cast Iron.

(1) Iron castings may be welded with a carbon arc, a cast iron rod, and a cast iron welding flux. The joint should be preheated by moving the carbon electrodes along the surface, thereby preventing too rapid cooling after welding. The molten–puddle of metal can be worked with the carbon electrode so as to move any slag or oxides that are formed to the surface. Welds made with the carbon arc cool more slowly and are not as hard as those made with the metal arc and a cast iron electrode. The welds are machinable.

6.3 ELECTRIC ARC WELDING OF NONFERROUS METALS.

6.3.1 Aluminum Welding.

a. General.

(1) Aluminum and aluminum alloys can be satisfactorily welded by GTAW and GMAW welding processes. The principal advantage of using arc welding processes is that a highly concentrated heating zone is obtained with the arc and, for this reason, excessive expansion and distortion of the metal are prevented.

b. GTAW and GMAW.

(1) Plate edge preparation.

(a) In general, the design of welded joints for aluminum is quite consistent with that for steel joints. However, because of the higher fluidity of aluminum under the welding arc, some important general principles should be kept in mind. In the lighter gages of aluminum sheet, less groove spacing is advantageous when weld dilution is not a factor. The controlling criterion is joint preparation. A special design V groove that is applicable to aluminum is shown in figure 6–44. This type of joint is excellent where welding can be done from one side only and where a smooth, penetrating bead is desired. The effectiveness of this particular design depends upon surface tension and should be applied on all material thicknesses over 1/8 inch. The bottom of the special V groove must be wide enough to contain the root pass completely. This necessitates adding a relatively large amount of filler alloy to fill the groove, but it results in excellent control of penetration and sound root pass welds. This edge preparation can be employed for welding in all positions with elimination of difficulties due to burn through or over penetration in the overhead and horizontal welding positions. It is applicable to all weldable base alloys and all filler alloys.

c. Welding Aluminum Castings.

(1) Aluminum castings that have been heat treated should not be welded unless facilities for reheating after welding are available.

(2) Large castings or those of an intricate design should be preheated slowly and uniformly in a suitable furnace to between 500– and 700–F (260– and 371–C). Small castings or those with thin sections may be preheated with a torch.

(3) Before welding, the surface of the aluminum should be carefully cleaned (paragraph 4.9.5) and if the casting is heavy, the crack should be tooled out to form a V.

6.4 WELDING OF TITANIUM AND TITANIUM ALLOYS.

6.4.1 General. The following procedures and requirements are for fusion welding of titanium and titanium alloys. Reference to these procedures shall be made when fusion welding of titanium is called for, but shall not supersede applicable engineering documents. All welding on titanium and titanium alloys shall be accomplished by personnel who have demonstrated proficiency in welding according to MIL–STD–1595.

NOTE

Where the requirements of an engineering document differ from this manual, the requirements of the engineering document shall apply.

6.4.2 MATERIALS AND EQUIPMENT.

a. Special tools and equipment required are as follows:

(1) Positioning fixtures and clamps.

(2) Welding chamber capable of producing a controlled atmosphere.

(3) Power supply capable of delivering direct current, straight polarity with superimposed high–frequency current.

b. Special materials required are as follows:

(1) Gas, shielding inert.

(2) Argon, purity 99.99% or higher and a dew point of minus 75–F or dryer.

(3) Electrodes, tungsten, EWTH–1 and EWTH–2.

(4) Filler material (welding wire).

(5) Cleaning solvents.

(6) Rags, cleaning Class A commercial grade lint free.

6.4.3 PROCEDURES.

6.4.3.1 WELDMENT PREPARATION.

a. For welding titanium and titanium alloys, joint fit–up should be better than for welding other metals, because of the possibility of entrapping air in the joint. The root opening shall be 0.25T (T = thickness) of the thinnest metal in the joint or 0.62 in., whichever is less.

b. If titanium welding is to be accomplished outside the welding chamber (open air), joints must be carefully designed so that both the top and the underside of the weld will be shielded with an inert gas.

6.4.3.2 CLEANING OF WELDMENTS PRIOR TO WELDING.

a. The sensitivity of titanium and titanium alloys to embrittlement, impose limitations on the joining processes that may be used. Small amounts of carbon, oxygen, nitrogen, or hydrogen impair ductility and toughness of titanium and titanium alloy. Consequently, joining processes and procedures that minimize joint contamination must be used. Dirt, dust, grease, fingerprints, and a wide variety of other contaminants can also lead to embrittlement and porosity when the titanium or filler metal is not properly cleaned prior to welding.

TITANIUM CLEANING SEQUENCE

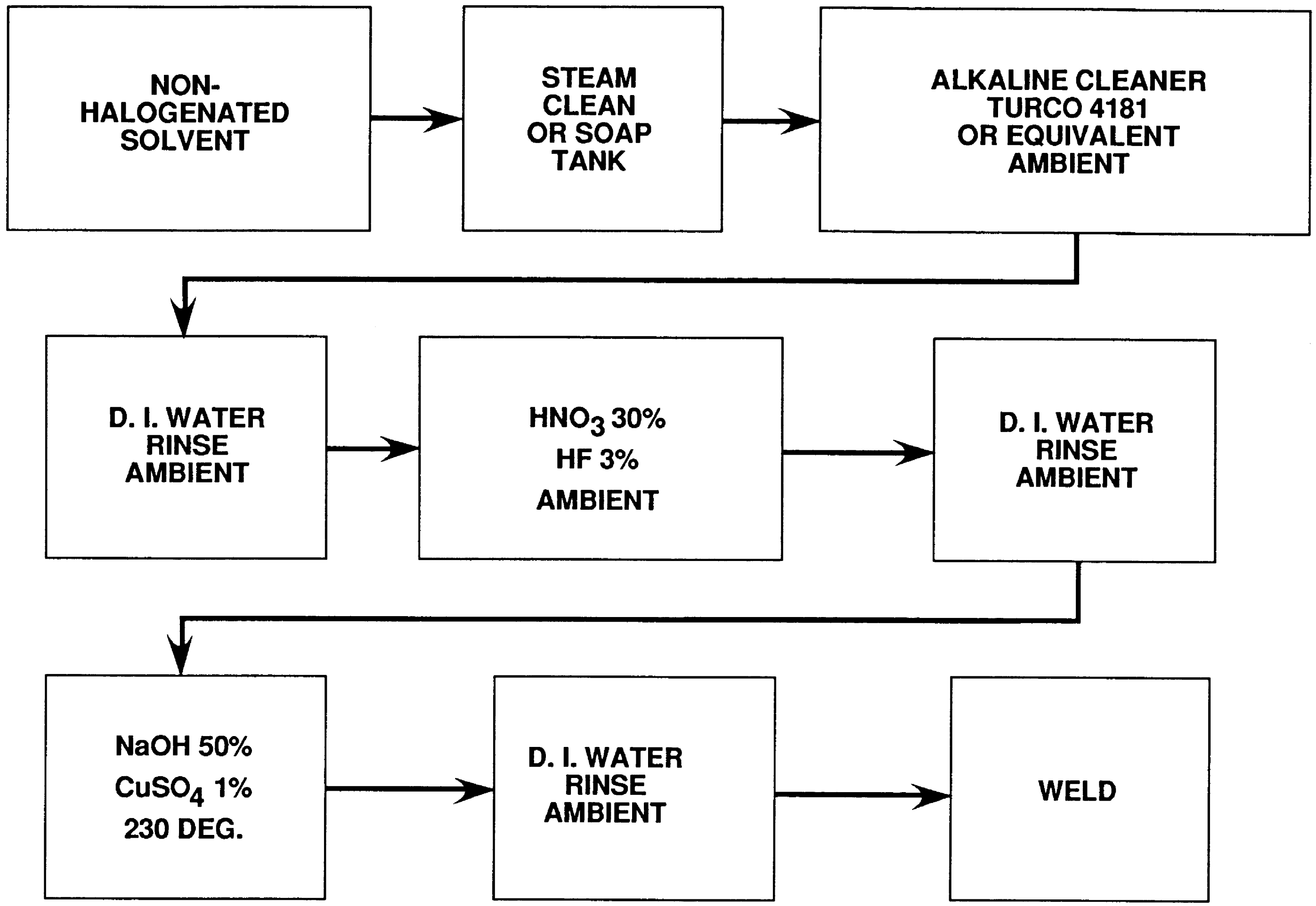


Figure 6-37. Titanium Cleaning Sequence

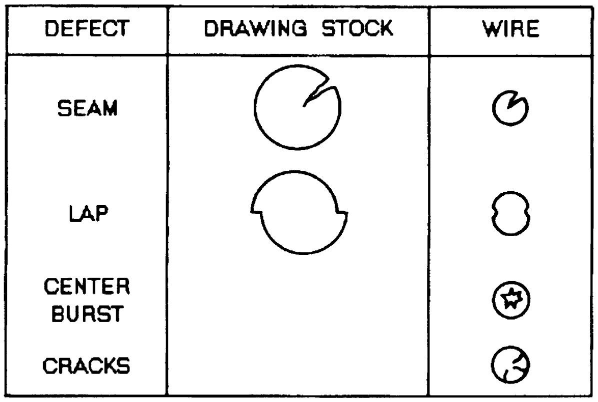


Figure 6–38. Welding Wire Defects

b. All weldments of titanium and titanium alloys shall be cleaned prior to welding. The following is an outline of the cleaning procedure.

WARNING

The following cleaning solutions are extremely hazardous. Use the proper hand, face, arm and body protection devices that will protect against organic solvents, caustic and acidic solutions. Refer to the local Safety and Health Office for guidelines.

(1) Titanium Cleaning. Figure 6–37 outlines the cleaning procedures for titanium. Table 6–6 is a list of required chemicals for this operation. The procedures include:

(a) Degreasing. Do not use halogenated solvents to degrease titanium. Halogens (chlorine, fluorine) can cause embrittlement. Clean with naphtha (TT–N–95) or Stoddard solvent (P–D–680).

(b) Detergent Clean. Clean the solvent residue using a mild soap solution (1 oz./gal.) in cold water.

(c) Scale Conditioning. Immerse in a cold solution of alkaline deruster at 8 to 12 oz./gallon for 10 to 60 minutes.

(d) Rinse. Rinse in deionized water.

(e) Descale. Immerse in a solution of 30% nitric acid and 1% hydrofluoric acid for 1/2 to 1–1/2 minutes.

(f) Rinse. Rinse in deionized water.

(g) Inspect for cleanliness. If not clean, proceed to subparagraph (h).

(h) Scale Conditioning. Immerse in a hot (230–F) solution of 50% sodium hydroxide and 1% copper sulfate for 30 to 60 minutes. Repeat steps (d) through (g).

(i) Final Rinse. Rinse in deionized water.

c. All titanium and titanium alloys, shall be placed in clean polyethylene bags LP–378, MIL–P–22191, or MIL–B–121 Grade ”A” (Barrier paper) immediately after cleaning.

d. Parts being removed from sealed containers, after cleaning and for welding shall be handled with clean (lint free) white gloves. Gloves used for handling titanium shall not be used for handling tools and other equipment.

(1) If parts have been in storage (sealed) more than seven days recleaning may be required.

(2) Parts that have been sheared shall have the sheared edges mechanically cleaned prior to the cleaning operation of paragraph 6.4.3.2b(1).

e. Immediately prior to loading fixtures (open air or chamber) weldments shall have the faying edges wiped (degreased) with a clean isopropyl alcohol moist cloth (lint free) or other approved solvent.

f. Tooling that comes in contact with parts, in the weld zone shall be free of oxides, and cleaned by wiping with a cloth (lint free) moistened with isopropyl alcohol prior to use.

Table 6–6. Titanium Cleaning Materials

NOMENCLATURE	NATIONAL/LOCAL STOCK NUMBER	UNIT–ISSUE	UNIT SIZE
Nitric Acid O–N–350 HNO3	00–236–5670	CB	6 1/2
Hydrofluoric Acid (O–H–795) HF	00–236–5671	DR	20 gal
Copper II Sulfate or Cupric Sulfate (O–C–828) CuSO4	00–236–5680	DR	100 lb
Alkaline Cleaner* Turco 4181	00–213–8797	CO	125 lb
Sodium Hydroxide (0–5–598) NaOH	00–270–8177	CO	13 oz
	00–174–6581	DR	100 lb

Table 6–7. Stress Relief Time and Temperature

BASE METAL	FILLERWIRE	STRESS RELIEVE	TIME
1. Comm Pure	AMS 4951	800–1000–F	1 hr air cool
2. TI. 5AL—2.5 sn	AMS4953	1000–2000–F	1 hr air cool
3. TI. 6AL–4V	AMS4954A	1200–F	5 hrs air cool
4. TI. 8AL–1Nb—1V	AMS4955	1300–F	30 min air cool

6.4.3.3 Filler Metal. Filler metal shall be per Table 6–7 unless specified on applicable engineering drawing.

a. Filler wire that has been contaminated by long exposure to shop atmosphere or has come in contact with oil, grease, dirt or other foreign matter, shall be cleaned in accordance with applicable engineering directives per paragraph 6.4.3.2b(1). Filler metal shall be considered contaminated if a residue is formed on a clean white cloth (lint free) that has been tightly held and drawn over a sample piece of wire. If the test proves negative and contamination is still suspected a section of wire shall be metallurgically inspected at a magnification of 50X or greater. Die drawing compound in crevices or folds shall be grounds for rejection or further processing and testing. See Figure 6–38 for types of titanium welding wire defects.

b. Filler wire shall be stored in moisture proof containers. Filler wire removed from moisture proof containers for production use shall not be returned to storage containers unless cleaned in accordance with the procedure outlined in paragraph 6.4.3.2b(1).

6.4.3.4 Certification of Equipment. Certification of the welding chamber, plastic bags, or local purging equipment shall consist of making acceptable test weld coupons, joined by a welder that has a certificate of proficiency in accordance with MIL–STD–1595. Test weld coupons shall have a minimum of 6 inches of weld for sheet or plate, and 9 inches of weld for joined pipe. Test coupons shall conform to the requirements of this specification.

a. Test coupons shall be submitted to any NADEP Materials Engineering Laboratories listed in Table 3–6 for certification and/or evaluation after major repairs to chamber pumps, motors, valves, plumbing, seals or glass. A log of certification date shall be maintained by shop foreman or supervisor.

6.4.3.5 Electrodes. Non–consumable electrode tips shall be ground to a sharp point, with a taper three to six diameters long.

a. Prior to regrinding, non–consumable electrodes that have been contaminated 1/4 to 3/8 inch shall be broached from the contaminated end.

6.4.3.6 SHIELDING GAS.

a. Argon is the preferred shielding gas and shall be used in combination with helium only when authorized by Engineering Instructions.

b. Evidence of properly purged lines, chamber, torch and equipment is a bright metallic color on a weld test coupon. The weld metal colors for titanium, in increasing order of contamination are: bright silver, light straw, dark straw, light blue, dark blue, gray blue, gray and white loose powder. The two acceptable colors for titanium welds, and weld affected zones are bright silver and light straw. All other colors are not acceptable and are cause for rejection of the weldment.

c. Welds not welded in a chamber shall remain shielded on all heat affected sides of the joint until the temperature of the welded part drops below 600–F.

d. During open air manual welding operation the filler rod shall remain in the protective cover of the shielding gas. Should the filler rod be contaminated by removal from the shielding gas, at least one half inch shall be trimmed from the oxidized end.

e. Welding shall be accomplished in a draft free area to prevent dispersion of the shielding gas and contamination of the weld bead. The area shall be dust and lint free.

6.4.3.7 Alignment of Butt Joints. Unless otherwise specified on the drawing, when manual welding, cross section alignment of sheet, plate or tubing surfaces adjacent to the butt weld joint shall be within 0.010 inch or 10% of the thickness of the material in the joint or whichever is less.

6.4.3.8 Alignment of Mating Parts. Mating–parts shall join together so that the gaps between them, due to the irregularity of mating surfaces or edges, shall not exceed 25% of the thinner part, or 1/16 inch or whichever is less. Faying edges that have shear marks shall be draw filed. Clean parts after draw filing per paragraph 6.4.3.2b(1).

6.4.4 BACK–UP BARS: Back–up bars (chilling or otherwise) shall be made of copper, (deoxidized) aluminum, or stainless steel machined so that no part of the back–up bars come in contact with the molten weld puddle, drop–thru reinforcement, or bead reinforcement.

6.4.4.1 Tack welds may be used to hold the mating parts prior to completing the weld operation, but shall be of minimum size and shall be free of defects. Tack welders shall be certified per MIL–STD–1595.

6.4.4.2 WELD CHARACTERISTICS.

a. Drop–thru shall not be accepted when welding titanium above 0.050 inch in thickness.

NOTE

Drop–thru is the fusion of the full thickness of the base metal in areas other than those where 100% joint penetration is a requirement. Refer to AWS A 3.0.

b. Butt and outside corner joints welded from one side shall show complete joint penetration to the degree that a small bead is formed on side opposite that being welded, paragraph 6.4.4.2f(1) and 6.4.4.2f(3).

c. 100% corner fusion is required on lap and fillet welds if the joint angle is 90_ or greater.

d. Complete corner fusion on fillet weld joints with an acute angle is not required. Lack of fusion shall be at the root of the weld only.

e. All welds shall fair into the adjacent metal on gradual smooth curves.

f. Weld bead size shall meet the requirements specified in the following paragraphs.

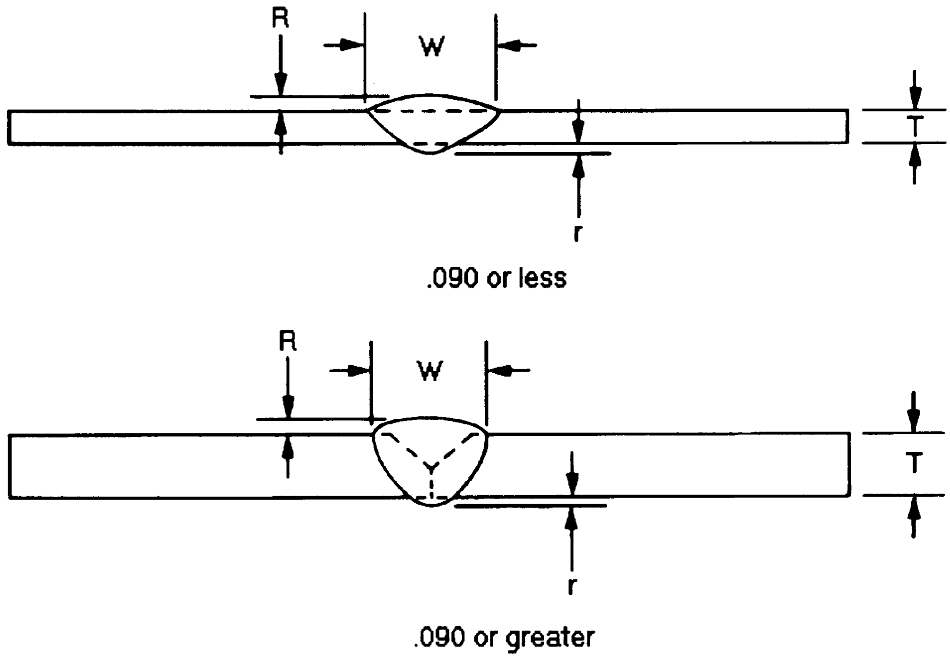


Figure 6-39. Butt Weld Bead Size, Welded From One Side Only

(1) Butt weld bead size, welded from one side only (shown in figure 6-39):

(a) Bead width "W" shall be the minimum necessary to obtain the penetration required per paragraph 6.4.4.2.

(b) For thickness of 0.090 in. or less, the face reinforcement "R" plus the root reinforcement "r" shall not exceed the thickness "T" unless otherwise specified on the engineering drawing.

(c) For thickness greater than 0.090 in., the face reinforcement "R" shall not exceed 0.5T or 1/8 inch, whichever is less, unless otherwise specified on the engineering drawing. The root reinforcement "r" shall not exceed 1/4T or 3/32 inch, whichever is less, unless otherwise specified on the engineering drawing.

(2) Butt weld bead size, welded from both sides (shown in figure 6-40):

(a) Bead width "W" shall be the minimum necessary to obtain the required fusion and penetration.

(b) Reinforcement "R" should be 0.1T to 0.3T of the thickness "T" but not exceeding 1/8 inch unless otherwise specified on the engineering drawing.

(3) Outside corner weld bead size (shown in figure 6-41):

(a) Weld bead "W" shall be the minimum necessary to obtain the penetration required per paragraph 6.4.4.2.

(b) Reinforcement "r" shall require evidence of penetration only.

(4) Lap joint bead size (shown in figure 6-42):

(a) "W" is determined by "A" and "B". The minimum value for "W" is 1.5T based on the thinner sheet.

(b) "C" equals 0.75T minimum based on the thinnest sheet (maximum 0.80).

(c) "A" or "B", whichever is smaller, shall equal or exceed the thickness of the thinnest material.

(d) "A" is greater than "B" when T2 equals T1 or when T2 is greater than T1.

(e) ”B” is greater than ”A”, or ”B” equals ”A” when T1 is greater than T2.

(5) Tee joint bead size (shown in figure 6–43):

(a) ”W” is determined by ”A” and ”B”. The minimum value for ”W” is 1.5T based on the thinner metal.

(b) ”C” is 0.75T minimum based on the thinner material.

(c) ”A” or ”B”, whichever is smaller, shall equal or exceed the thickness of the thinner material.

(d) ”A” is greater than ”B” when T2 is greater than T1.

(e) ”B” equals ”A”, or ”B” is greater than ”A” when T1 is greater than T2.

(f) ”A” is approximately equal to ”B” when T1 equals T2.

6.4.5 DEFECTS.

a. General.

(1) Each weld shall be inspected visually for defects, and by one or more of the following methods.

(2) Fluorescent penetrant inspection (including liquid penetrant inspection).

(3) Radiographic inspection –Weld deposit quality requirements.

b. When the applicable engineering drawing calls for radiographic inspection, the welds shall be inspected in accordance with MIL–STD–453. Weldments containing defects of the following types and proportions are not acceptable.

(1) Cracks of any size in the weld metal or adjacent to the weld.

(2) Inclusions (including tungsten), unfused areas and/or lack of weld joint preparation.

(3) Single porosity cavities measuring 10% of the thickness of the thinnest material in the joint or 0.020 whichever is the lesser. Inter–connected porosity shall be considered as a single cavity. Measurement of all porosity cavities shall be based on their largest dimension.

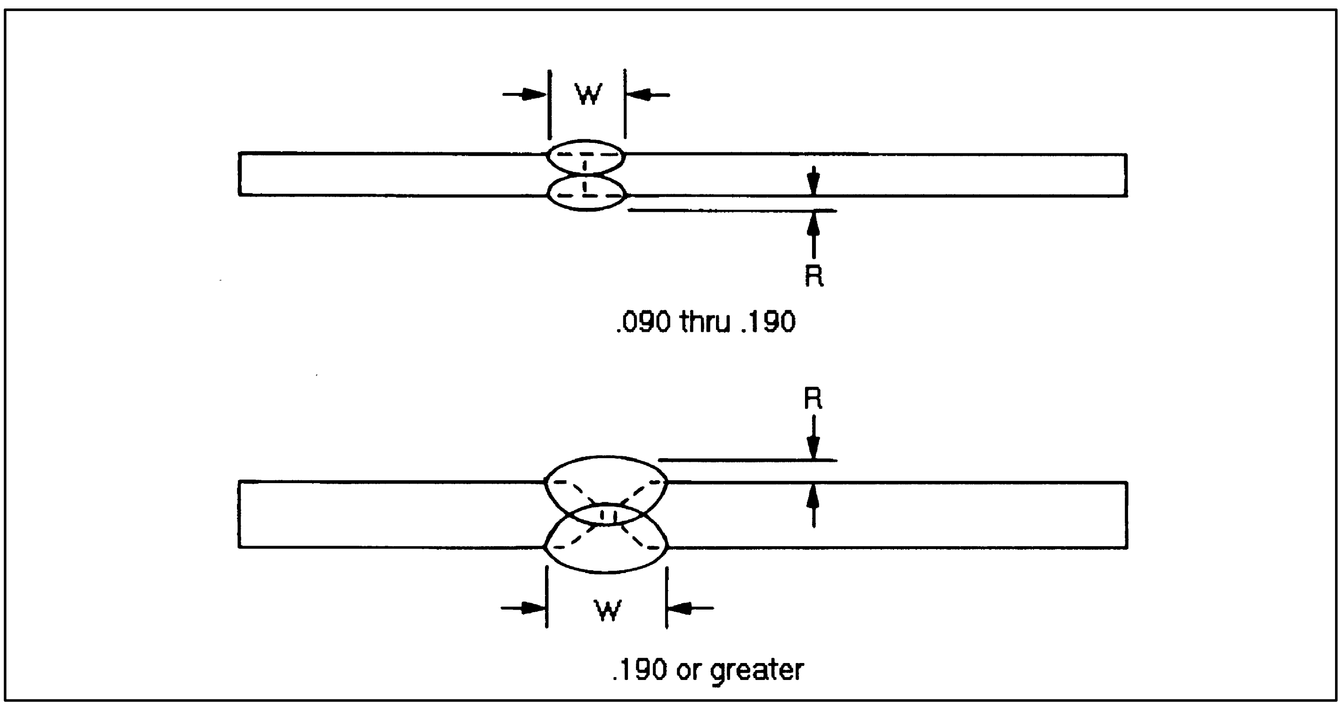


Figure 6–40. Butt Weld Bead Size, Welded From Both Sides

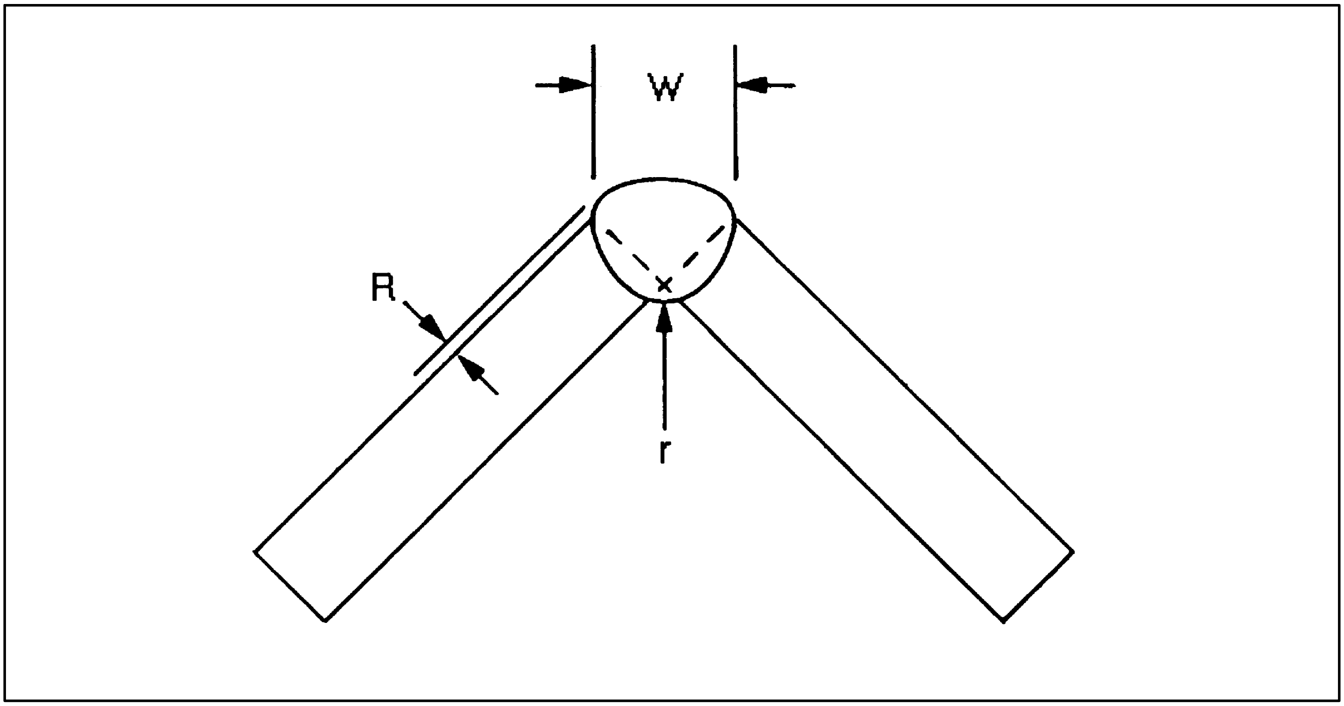


Figure 6-41. Outside Corner Weld Bead Size

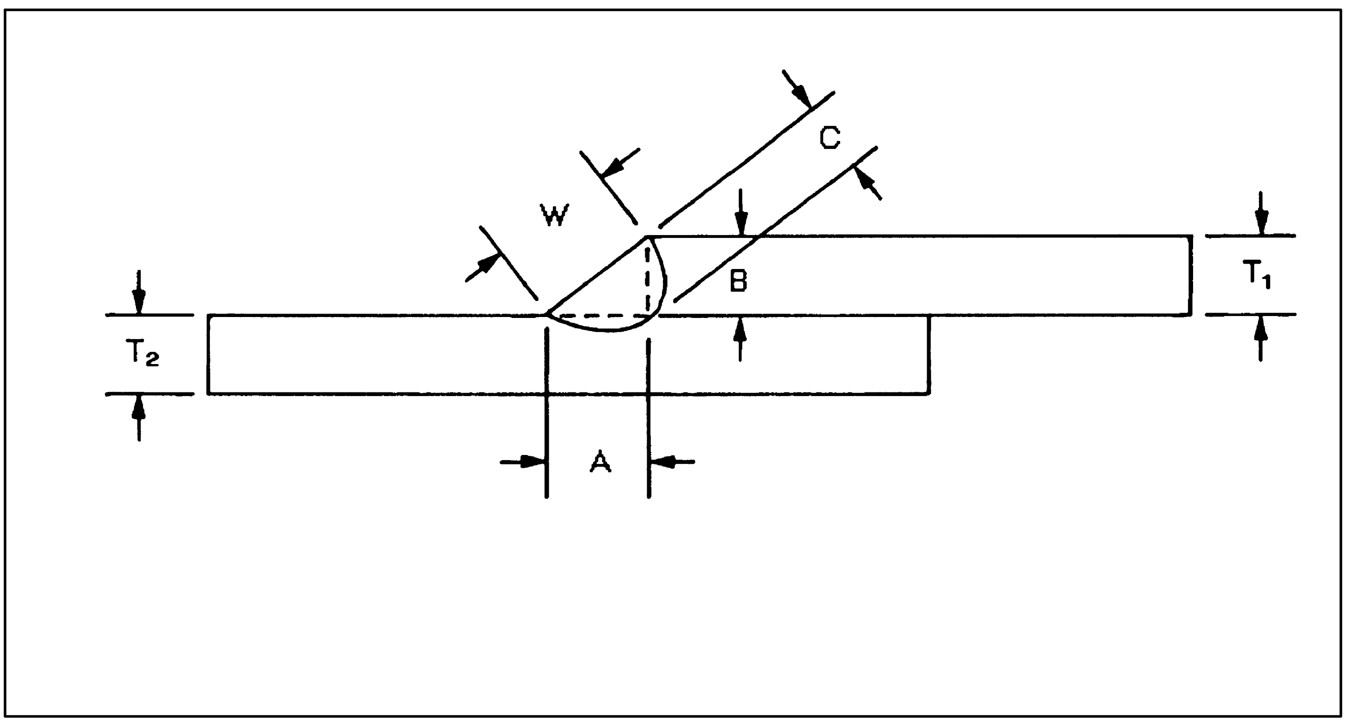


Figure 6-42. Lap Joint Bead Size

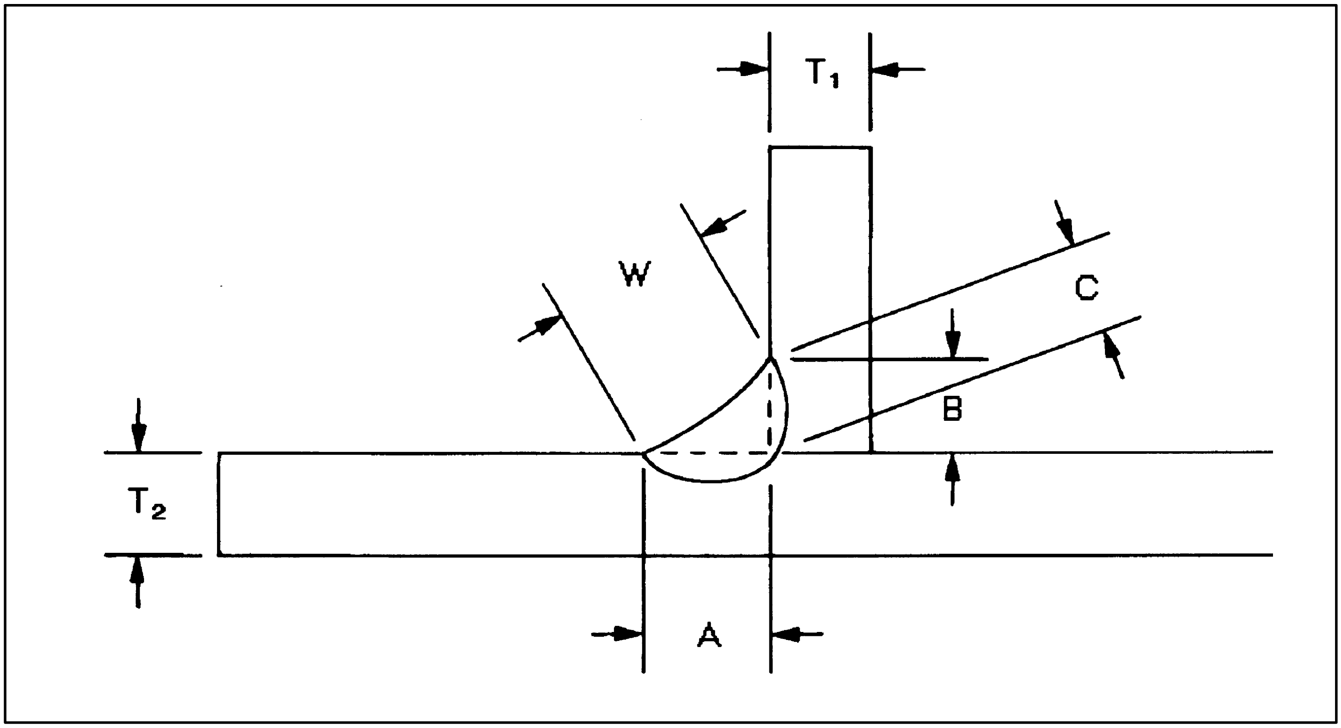


Figure 6–43. Tee Joint Bead Size

(4) Three or more single porosity cavities in alignment, any one of which measures 10% of "T" of the thinner material or 0.001 inch, whichever is the lesser, in any lineal inch or less of weld.

(5) Scattered porosity, when the sum of the dimensions of all the cavities in any 50T length of weld equals 0.5T or greater.

NOTE

Weld deposits which will receive subsequent forming operations shall be radiographically inspected prior to and after the forming operation.

6.4.5.1 Surface Defects. Welds containing the following defects shall be unacceptable.

a. Cracks in the base metal or weld bead.

b. Craters containing cracks, porosity open to the surface, concavity extending below the surface of the base metal, or lack of penetration below the crater surface.

c. Lack of fusion between the weld metal and the base metal.

d. Fillet or corner craters which extend below the minimum throat dimension.

e. Overlap on a weld deposit or weld toe.

f. Atmospheric contamination caused by inadequate inert gas coverage. (Evidenced by the presence of oxide discoloration on or adjacent to the weld bead).

g. Pin holes or porosity open to the surface.

h. Penetration defects such as under bead concavity, suck back and incomplete penetration.

i. Thinning and undercutting which removes metal adjacent to the weld by any means below the limits of the engineering drawing.

j. The previously listed defects may be weld repaired as per paragraph 6.4.4.2, providing that the repaired weld does not exceed these dimensions shown.

6.4.5.2 Subsurface Defects. Subsurface defects (radiographic inspection). Welds containing any of the following subsurface defects shall be unacceptable when radiographic inspection is specified in the engineering drawing.

a. Cracks in the welds or base metal.

b. Lack of fusion between multi-pass welds or between weld and base metal.

c. Incomplete penetration.

d. Inclusions such as slag (other than chamber welding) oxides or tungsten.

e. Porosity, gas holes and cavities.

6.5 REPAIR OF DEFECTIVE WELDS IN BOTH OLD AND NEW PARTS.

a. Removal of weld area defects.

(1) Weld defects shall be removed by using abrasive or cutting tools which will not embed foreign material into the base metal surface.

(2) Temperatures exceeding 500°F shall be avoided when removing defects, by grinding or cutting.

(3) All rotary filing, grinding or sanding, and wire brushing (stainless steel wire, brush-wire diameters not to exceed 0.020 inch) shall be done without the use of oil, water or other cutting fluids.

b. Tooling used for titanium shall not be used on other metals.

c. Inspection shall determine by visual, radiographic, or liquid penetrant means that the weld defect has been removed.

d. Prior to repair welding, the weld repair area shall be cleaned per paragraph 6.4.3.2.

e. Repair welds and new part welding shall be accomplished by Gas Tungsten Arc Welding (GTAW) in an inert gas atmosphere.

f. Covering an unacceptable weld by a second weld pass, without prior removal of the defective area or weld bead, is prohibited.

g. If an undercut area forms a smooth contoured groove at the bottom and the weld is otherwise sound, the weld may be repaired by a second bead joining the original weld and base metal without removing metal from the defect.

h. Cracks extending into the base metal shall not be repaired without engineering approval.

i. Stress Relieving.

(1) All titanium and titanium alloys shall be stress relieved after weld unless otherwise specified by an engineering directive. See table 6-7 for the time and temperature for proper stress relief.

6.6 OXYACETYLENE WELDING PROCESS AND TECHNIQUES.

6.6.1 General Welding Procedure.

a. The edges to be welded by the oxyacetylene welding process must be properly prepared, aligned, and correctly spaced.

b. A good weld requires the proper torch tip, correct flame adjustment, and skillful rod and torch manipulation.

c. Under some conditions special procedures are necessary such as preheating, slow cooling, or stress relieving.

d. When welding certain metals a flux is required to remove oxides and slag from the molten metal, and to protect the puddle from the action of atmospheric oxygen.

e. When welding light sheet metal the edges are normally prepared by flanging. Light sheet metal requires no filler. In welding heavier sheets and plates filler metals are required, and the edges being welded must be prepared so that the filler metal will penetrate to the joint root.

NOTE

> Oxygen pressures are approximately the same as acetylene pressures in the balanced pressure type torch. Pressures for specific types of mixing heads and tips are specified by the manufacturer.

6.6.2 Working Pressures for Welding Operations. The required working pressure increases as the tip orifice increases. The relation between the tip number and the diameter of the orifice may vary with different manufacturers. The smaller number always indicates the smaller diameter. For the approximate relation between the tip number and the required oxygen and acetylene pressures, see tables 6-8 and 6-9.

6.6.2.1 Flame Adjustment and Flame Types.

a. Lighting the Torch.

(1) To start the welding torch hold it so as to direct the flame away from the operator, gas cylinders, hose, or any flammable material. Open the acetylene valve 1/4 turn and ignite the gas by striking the sparklighter in front of the tip.

(2) Since the oxygen valve is closed the acetylene is burned by the oxygen in the air. There is not sufficient oxygen to provide complete combustion so the flame is smoky and produces a soot of fine unburned carbon. Continue to open the acetylene valve slowly until the flame burns clean. The acetylene flame is long, bushy and has a yellowish color. This pure acetylene flame is unsuitable for welding.

(3) Slowly open the oxygen valve. The flame changes to a bluish–white and forms a bright inner cone surrounded by an outer flame envelope or sheath flame. The inner cone develops the high temperature required for welding. The outer envelope contains varying amounts of incandescent carbon soot, depending on the proportions of oxygen and acetylene in the flame.

Table 6–8. Low Pressure or Injector Type Torch

Tip Size, Number	Oxygen, psi	Acetylene. psi
0	1	9
1	1	9
2	1	10
3	1	10
4	1	11
5	1	12
6	1	14
7	1	16
8	1	19
10	1	21

Table 6–9. Balanced Pressure Type Torch

Tip Size, Number	Acetylene, psi
1	2
1	2
3	3
4	3
5	3.5
6	3.5
7	5
8	7
9	9
10	12

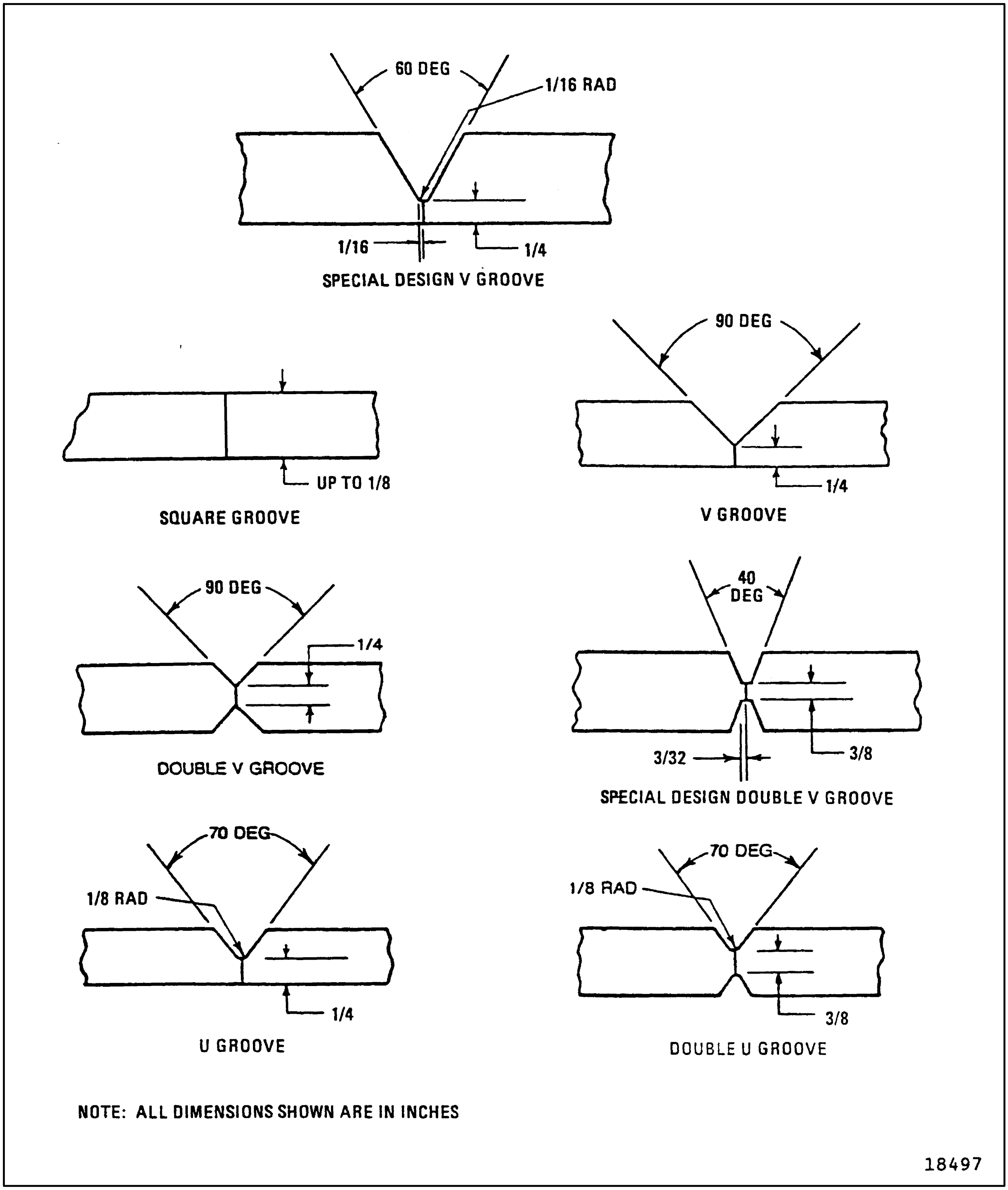


Figure 6-44. Joint Design for Aluminum Plates

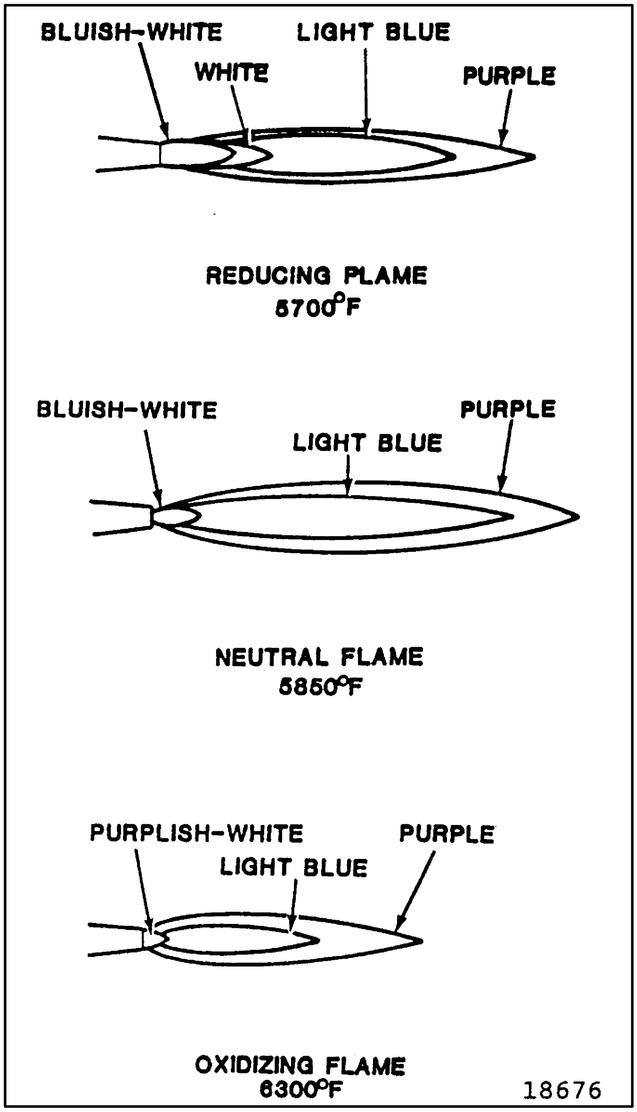


Figure 6–45. Oxyacetylene Flames

(4) The temperature produced is so high (up to 6,300−F (3,482−C)) that the products of complete combustion (i.e., carbon dioxide and water) are decomposed into their elements. Acetylene burning in the inner cone with oxygen supplied by the torch forms carbon monoxide and hydrogen. As these gases cool from the high temperatures of the inner cone they burn completely with the oxygen supplied by the surrounding air and form the lower temperature sheath flame. The carbon monoxide burns to form carbon dioxide and hydrogen burns to form water vapor. Since the inner cone contains only carbon monoxide and hydrogen, which are reducing in character (i.e., able to combine with and remove oxygen), oxidation of the metal will not occur within this zone.

b. Types of Flames.

(1) General. Three types of oxyacetylene flames, shown in figure 6–45 are commonly used for welding. These are neutral, reducing (or carburizing), and oxidizing flames.

(2) Neutral flame.

(a) The welding flame should be adjusted to neutral before either the carburizing or oxidizing flame mixture is set. There are two clearly defined zones in the neutral flame. The inner zone consists of a luminous cone that is bluish–white. Surrounding this is a light blue flame envelope or sheath. This neutral flame is obtained by starting with an excess acetylene flame in which there is a "feather" extension of the inner cone. When the flow of acetylene is decreased or the flow of oxygen increased the feather will tend to disappear. The neutral flame begins when the feather disappears.

(b) The neutral or balanced flame is obtained when the mixed torch gas consists of approximately one volume of oxygen and one volume of acetylene. It is obtained by gradually opening the oxygen valve to shorten the acetylene flame until a clearly defined inner cone is visible. For a strictly neutral flame no whitish streamers should be present at the end of the cone. In some cases it is desirable to leave a slight acetylene streamer or "feather" (1/16 to 1/8 inch long) at the end of the cone to insure that the flame is not oxidizing. The volume ratio of oxygen to acetylene in forming a neutral flame is 1.04 to l.14. This flame adjustment is used for most welding operations and for preheating during cutting operations. When welding steel with this flame the molten metal puddle is quiet and clear. The metal flows easily without boiling, foaming or sparking.

(c) In the neutral flame the temperature at the inner cone tip is approximately 5,850−F (3,232−C), while at the end of the outer sheath or envelope the temperature drops to approximately 2,300−F (l,260−C). This variation within the flame permits some temperature control when making a weld. The position of the flame to the molten puddle can be changed, and the heat controlled in this manner.

(3) Reducing or carburizing flame.

(a) The reducing or carburizing flame is obtained when slightly less than one volume of oxygen is mixed with one volume of acetylene. The volume ratio is 0.85 to 0.95. This flame is obtained by first adjusting to neutral and then slowly opening the acetylene valve until an acetylene streamer or ”feather” is at the end of the inner cone. The length of this excess streamer indicates the degree of flame carburization. For most welding operations this streamer should be no more than half the length of the inner cone.

(b) The reducing or carburizing flame can always be recognized by the presence of three distinct flame zones. There is a clearly defined bluish–white inner cone, a white intermediate cone indicating the amount of excess acetylene, and a light blue outer flame envelope. This type of flame burns with a coarse rushing sound and has a temperature of approximately 5,700–F (3,l49–C) at the inner cone tips.

(c) When a strongly carburizing flame is used for welding, the metal boils and is not clear. The steel is absorbing carbon from the flame then gives off heat which causes the metal to boil. When cold the weld has the properties of high carbon steel, being brittle and subject to cracking.

(d) A slight feather flame of acetylene is sometimes used for backhand welding (paragraph 6.6.6). A carburizing flame is advantageous for welding high carbon steel for hard facing operations, and for welding such nonferrous alloys as nickel and monel. When used in silver solder and soft solder operations only the intermediate and outer flame cones are used. They impart a low temperature **S**soaking heat to the parts being soldered.

(4) Oxidizing flame.

(a) The oxidizing flame is produced when slightly more than one volume of oxygen is mixed with one volume of acetylene. The volume ratio is 1.7 to 1.15. To obtain this type of flame the torch should first be adjusted to give a neutral flame. The flow of oxygen is then increased until the inner cone is shortened to about one–tenth of its original length. When the flame is properly adjusted the inner cone is pointed and slightly purple. An oxidizing flame can also be recognized by its distinct hissing sound. The temperature of this flame is approximately 6,300–F (3,482–C) at the inner cone tip.

(b) When applied to steel an oxidizing flame causes the molten metal to foam and give off sparks. This indicates that the excess oxygen is combining with the steel and burning it. An oxidizing flame should not be used for welding steel because the deposited metal will be porous, oxidized, and brittle. This flame will ruin most metals and should be avoided, except as noted in (c) below.

(c) A slightly oxidizing flame is used in torch brazing of steel and cast iron. A stronger oxidizing flame is used in the welding of brass or bronze.

(d) In most cases the amount of excess oxygen used in this flame must be determined by observing the action of the flame on the molten metal.

6.6.3 <u>Oxyacetylene Welding Rods</u>.

a. The welding rod which is melted into the welded joint plays an important part in the quality of the finished weld. Good welding rods are designed to permit free flowing metal which will unite readily with the base metal to produce sound, clean welds of the correct composition.

b. Welding rods are made for various types of carbon steel, for cast iron, aluminum, bronze, stainless steel and other metals, and for hard surfacing.

6.6.4 <u>Oxyacetylene Welding Fluxes</u>.

a. The oxides of all the ordinary commercial metals and alloys except steel have higher melting points than the metals themselves and are usually pasty (some are even infusible) when the metal is quite fluid and at the proper welding temperature. An efficient flux will combine with oxides to form a fusible slag having a melting point lower than the metal so that it will flow away from the immediate field of action. This slag, incidentally, forms a coating over the molten metal and thus serves as a protection against atmospheric oxidation. The chemical characteristics and melting points of the oxides of different metals vary greatly and therefore there can be no one flux that will be satisfactory for all metals.

b. The melting point of a flux must be lower than that of either the metal or the oxides formed, so that it will be liquid. The ideal flux has exactly the right fluidity at the welding temperature and thus tends to blanket the molten metal from atmospheric oxidation. Such a flux remains close to the weld area instead of flowing over the base metal for some distance from the weld.

c. Fluxes usually are packed in powder form in tin cans. Some of them lose their welding properties if exposed too long to the atmosphere, and in such cases small containers are best.

d. Fluxes differ in their composition according to the metals with which they are to be used. In cast iron welding a slag forms on the surface of the puddle and the flux serves to break this up. Equal parts of carbonate of soda and bicarbonate of soda make a good compound for this purpose. Nonferrous metals usually require a flux. Copper also requires a filler rod containing enough phosphorus to produce a metal free from oxides. Borax which has been melted and powdered is often used as a flux with copper alloys. A good flux is required with aluminum because there is a tendency for the heavy slag formed to mix with the melted aluminum and weaken the weld. For sheet aluminum welding, it is customary to dissolve the flux in water and apply it to the rod. After welding aluminum, all traces of the flux should be removed.

6.6.5 Forehand Welding.

a. In this method the welding rod precedes the torch. The torch is held at an angle of approximately 30 degrees from the vertical, in the direction of welding as shown in figure 6-46. The flame is pointed in the direction of welding and directed between the rod and the molten puddle. This position permits uniform preheating of the plate edges immediately ahead of the molten puddle. By moving the torch and the rod in opposite semicircular paths the heat can be carefully balanced to melt the end of the rod and the side walls of the plate into a uniformly distributed molten puddle. The moving flame melts off a short length of the rod and adds it to the molten puddle. The heat which is reflected backwards from the rod keeps the metal molten. The metal is distributed evenly to both edges being welded and to the deposited weld by the motion of the tip and rod.

b. This method is satisfactory for welding sheets and light plates in all positions. Some difficulties are encountered in welding heavier plates for the reasons given below:

(1) In forehand welding the edges of the plate must be beveled to provide a wide V with a 90 degree included angle. This edge preparation is necessary to insure satisfactory melting of the plate edges, good penetration, and fusion of the weld metal to the base metal.

(2) Because of this wide V a relatively large molten puddle is required. It is difficult to obtain a good joint when the puddle is too large.

6.6.6 Backhand Welding.

a. In this method the torch precedes the welding rod, as shown in figure 6-47. The torch is held at an angle of approximately 30 degrees from the vertical away from the direction of welding, with the flame directed at the molten puddle. The welding rod is between the flame and the molten puddle. This position requires less transverse motion than is used in forehand welding.

b. Backhand welding is used principally for welding heavy sections because it permits the use of narrower V's at the joint. A 60 degree included angle of bevel is sufficient for a good weld. In general there is less puddling, and less welding rod is used with this method than with the forehand method.

6.6.7 Multilayer Welding.

a. In single layer welding of thick metal the side walls of the V could be melted excessively, which results in a wide weld. Multilayer welding (figure 6-48) consists of depositing metal in two or more layers or passes. It is used in welding thick plates or pipe walls to avoid carrying a large puddle of molten metal, which is difficult to control.

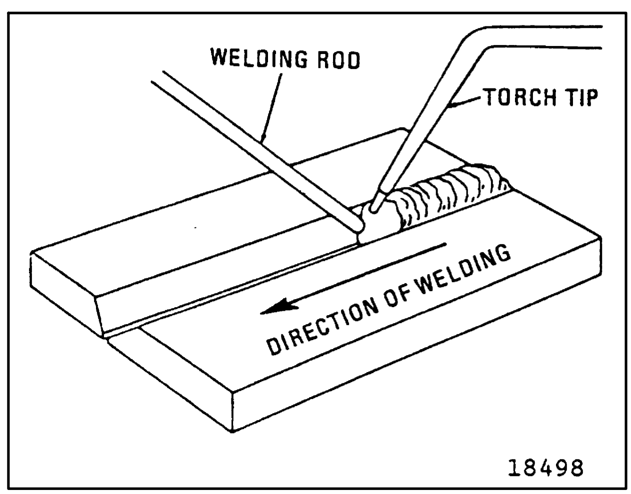


Figure 6-46. Forehand Welding

b. The multilayer method allows the welder to concentrate on getting good penetration at the root of the V in the first pass or layer. The final layer is easily controlled to obtain a good smooth surface.

c. This method permits the metal deposited in a given layer to be partly or wholly refined by the succeeding layers, and therefore improved in ductility. The lower layer of weld metal, after cooling to black heat, is reheated by the upper layer through the critical temperature range and then cooled, in effect being heat treated. In work where this added quality is desired in the top layer of the welded joint, an excess of weld metal is deposited on the finished weld and then machined off. The purpose of this last layer is simply to provide welding heat to refine the final layer of weld metal.

6.6.8 Fillet Welding.

a. A different welding technique is required for fillet welding than for butt joints because of the position of the parts to be welded. When welding is done in the horizontal position, the lower plate is continuous under the weld, and there is a tendency for the top plate to melt before the bottom plate. This can be avoided, however, by pointing the flame more at the bottom plate than at the edge of the upper plate. Both plates must reach the welding temperature at the same time.

b. In making the weld, a modified form of backhand technique should be used. The welding rod should be kept in the puddle between the completed portion of the weld and the flame, but the flame should be pointed ahead slightly in the direction in which the weld is being made and directed at the lower plate. To start welding, the flame should be concentrated on the lower plate until the metal is quite red and then should be directed so as to bring both plates to the welding temperature at the same time. It is important that the flame not be pointed directly at the inner corner so that the burning gases are reflected back around the tip, since this makes for pocketing in the weld and control of the puddle is difficult.

c. It is essential in this form of welding that fusion be obtained at the inside corner or root of the joint.

6.6.9 Flat Position Welding.

a. Weld Beads.

(1) In order to make satisfactory weld beads on a plate surface the flame motion, tip angle, and position of the welding flame above the molten puddle should be carefully maintained. The welding torch should be adjusted to give the proper type of flame for the particular metal being welded.

(2) Narrow weld beads are made by raising and lowering the welding flame with a slight circular motion while progressing forward. The tip should form an angle of approximately 45 degrees with the plate surface, and the flame should point in the welding direction (figures 6–49 and 6–50).

(3) To increase the depth of fusion either increase the angle between the tip and the plate surface or decrease the welding speed. The size of the puddle should not be too large because this will cause the flame to burn through the plate. A properly made weld bead, without the addition of filler rod, will be slightly below the upper surface of the plate, and a ridge will form on the underside to indicate full penetration (figure 6–49). A weld bead with filler rod shows a buildup on the surface of the plate.

(4) A small puddle should be formed on the surface when making a weld bead with a welding rod (figure 6–50). The welding rod is inserted into the puddle and then the base plate and rod are melted together. The torch should be moved slightly from side to side to obtain good fusion. By varying the speed of welding and the amount of metal deposited from the welding rod the size of the weld bead can be controlled to any desired limit.

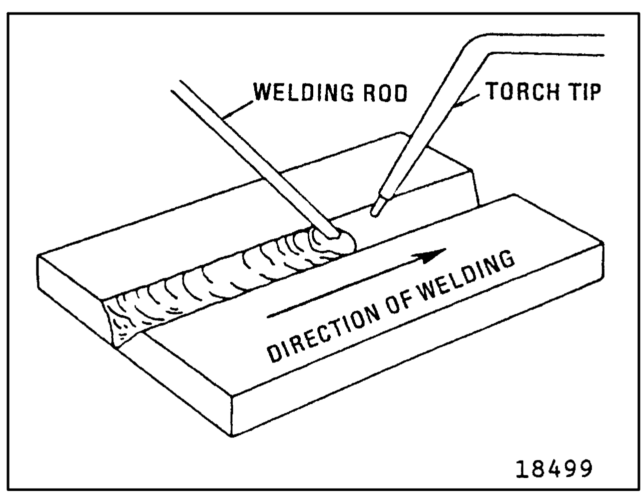


Figure 6–47. Backhand Welding

b. Butt Welds.

(1) Several types of joints are used to make butt welds in the flat position. These are illustrated in figures 6–52 and 6–53.

(2) Tack welds should be used to keep the heavier plates aligned. The lighter sheets should be spaced to allow for weld metal contraction and thus prevent warpage.

(3) The following guide should be used for selecting the number of passes (figure 6–48) in butt welding steel plates:

Plate thickness, inch	Number of passes
1/8 to 1/4	1
1/4 to 5/8	2
5/8 to 7/8	3
7/8 to 1 1/8	4

(4) The position of the welding rod and torch tip in making a flat position butt joint is shown in figure 6–51. The motion of the flame should be controlled so as to melt the side walls of the plates and enough of the welding rod to produce a puddle of the desired size. By oscillating the torch tip and welding rod a molten puddle of a given size can be carried along the joint at a speed which will ensure both complete penetration and sufficient filler metal to provide some reinforcement at the weld.

(5) Care should be taken not to overheat the molten puddle. This will result in burning the metal, porosity, and low strength in the completed weld.

6.6.9.1 Horizontal Position Welding.

a. It is a little more difficult to master butt welding in the horizontal position than in the flat position. This is due to the tendency of molten metal to flow to the lower side of the joint, while the heat from the torch rises to the upper side of the joint. The combination of these opposing factors makes it difficult to apply a uniform deposit to this joint.

b. Align the plates and tack weld at both ends (figure 6–54). The torch should move with a slight oscillation up and down to distribute the heat equally to both sides of the joint. A slight rolling motion should be applied to the rod. The torch movement and the movement of the rod are the same as before, a rolling motion up and down the width of the deposit, thereby holding the molten metal in a plastic state to prevent excessive flow of the metal to the lower side of the joint and permit faster solidification of the weld metal. This joint in horizontal position will require considerably more practice than the previous techniques. It is, however, important that the technique be mastered before passing on to other types of weld joints.

6.6.10 Vertical Position Welding.

a. When welding is done on a vertical surface the molten metal has a tendency to run downward and pile up. A weld that is not carefully made will result in a joint with excessive reinforcement at the lower end and some undercutting on the surface of the plates.

b. The flow of metal can be controlled by pointing the flame upward at an angle of 45 degrees to the plate, and holding the rod between the flame and the molten puddle (figure 6–55). The flow of gases from the inclined tip keeps the metal from sagging or falling and insures good penetration and fusion at the joint. Both the torch and welding rod should be oscillated to deposit a uniform bead. The welding rod should be held slightly above the center line of the joint, and the welding flame should sweep the molten metal across the joint to distribute it evenly.

c. Butt joints welded in the vertical position should be prepared for welding in the same manner as that required for welding in the flat position (paragraph 6.6.9b).

6.6.11 Overhead Position Welding.

a. Weld Beads. In overhead welding the metal deposited tends to drop or sag on the plate causing the bead to have a high crown. To overcome this difficulty the molten puddle should be kept small and enough filler metal should be added to obtain good fusion with some reinforcement at the bead. If the puddle becomes too large the flame should be removed for an instant to permit the weld metal to freeze. When welding light sheets the puddle size can be controlled by applying the heat equally to the base metal and filler rod.

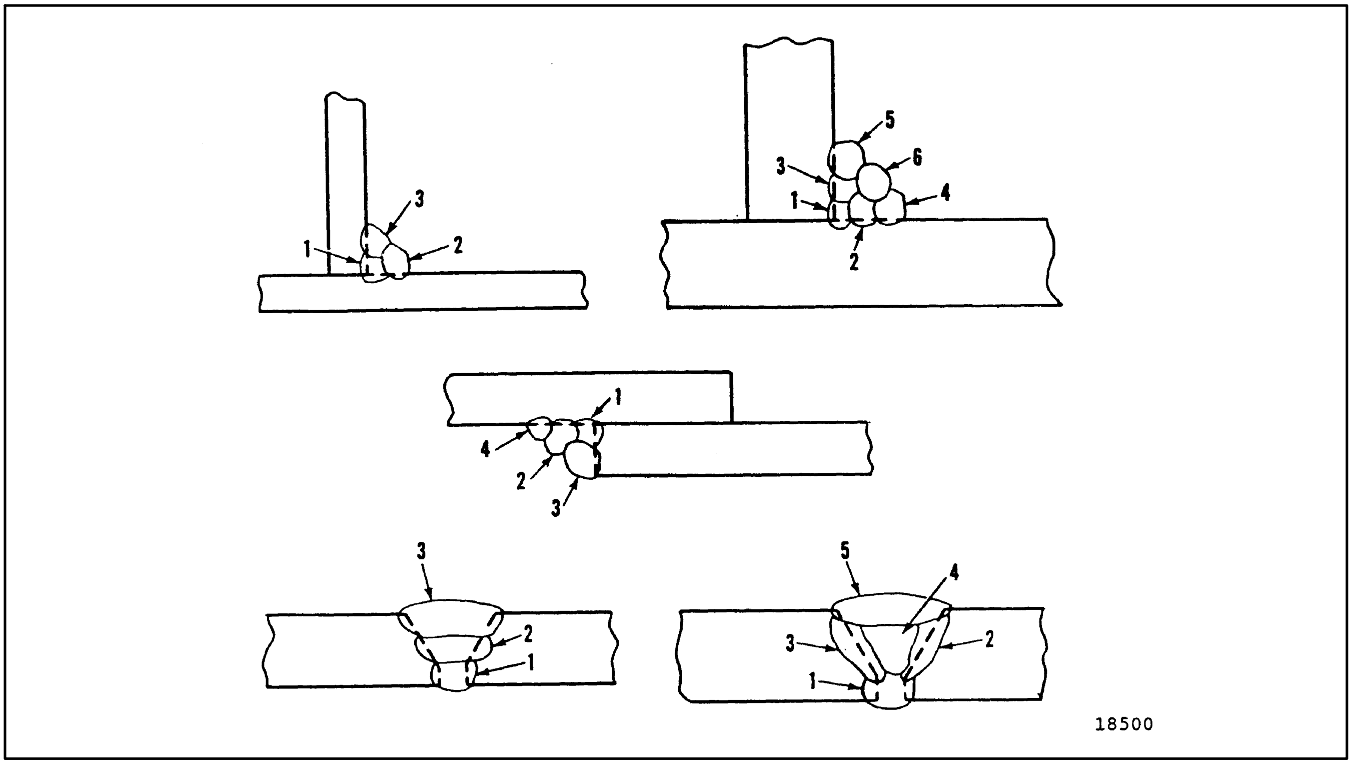


Figure 6-48. Sequences in Multilayer Welding

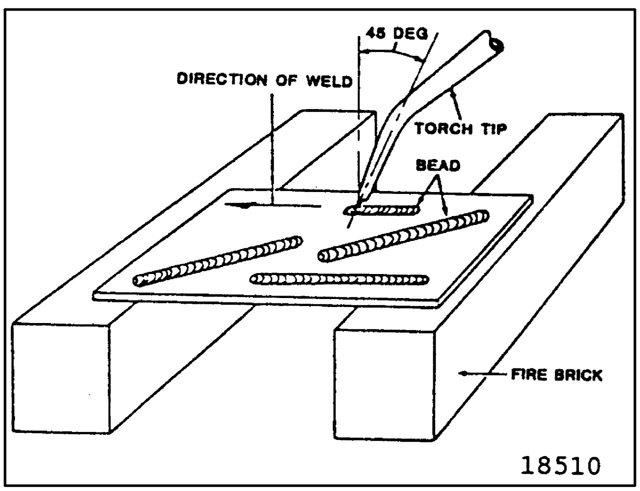


Figure 6-49. Welding Beads Without a Welding Rod

b. Butt Joints. The torch and welding rod position for welding overhead butt joints are shown in figure 6-56. The flame should be directed so as to melt both edges of the joint, and sufficient filler metal should be added to maintain an adequate puddle with sufficient reinforcement. The welding flame should support the molten metal and distribute it along the joint. Only a small puddle is required so a small welding rod should be used. Care should be taken to control the heat to avoid burning through the plates. This is particularly important when welding is done from one side only.

6.7 WELDING AND BRAZING FERROUS METALS.

6.7.1 Oxyacetylene Welding General.

a. Welding Sheet Metal.

(1) For welding purposes the term "sheet metal" is restricted to thicknesses of metals up to and including 1/8 inch.

(2) Welds in sheet metal up to l/16 inch thick can be made satisfactorily by flanging the edges at the joint. The flanges must be at least equal to the thickness of the metal. The edges should be aligned with the flanges in a vertical position and then tack welded every 5 or 6 inches. Heavy angles or bars should be clamped on each side of the joint to prevent distortion or buckling. The raised edges are equally melted by the welding flame. This produces a weld nearly flush with the sheet metal surface. By controlling the welding speed and the flame motion, good fusion to the underside of the sheet can be obtained without burning through. A plain square butt joint can also be made on sheet metal up to l/l6 inch thick by using a

rust–resisting copper–coated low carbon filler rod 1/16 inch in diameter. The method of aligning the joint and tacking the edges is the same as that used for welding flanged edge joints.

(3) Where it is necessary to make an inside edge or corner weld there is danger of burning through the sheet unless special care is taken to control the welding heat. Such welds can be made satisfactorily in sheet metal up to l/l6 inch thick by following the procedures below:

(a) Heat the end of a l/8 inch low carbon welding rod until approximately l/2 inch of the rod is molten.

(b) Hold the rod so that the molten end is above the joint to be welded.

(c) By sweeping the flame across the molten end of the rod the metal can be removed and deposited on the seam. The quantity of molten weld metal is relatively large as compared with the light gage sheet and its heat is sufficient to preheat the sheet metal. By passing the flame quickly back and forth the filler metal is distributed along the joint and the additional heat supplied by the flame will produce complete fusion. This method of welding can be used for making difficult repairs on automobile bodies, metal containers, and similar applications.

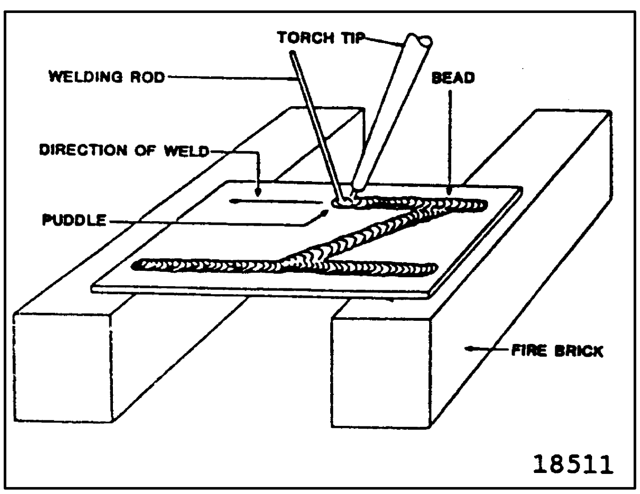


Figure 6–50. Welding Beads With a Welding Rod

(4) For sheet metal 1/16 to 1/8 inch thick a butt joint, with a space of approximately 1/8 inch between the edges, should be prepared. A l/8 inch diameter copper–coated low carbon filler rod should be used. Sheet metal welding with a filler rod on butt joints should be done by the forehand method of welding.

b. Welding Steel.

(1) General. The term ”steel” may be applied to many ferrous metals which differ greatly in both chemical and physical properties. In general they may be divided into plain carbon and alloy groups. By following the proper procedures most steels can be successfully welded. However, parts fabricated by welding generally contain less than 0.30 percent carbon. Heat increases the carbon combining power of steel and care must be taken during all welding processes to avoid carbon pick–up.

(2) Welding process. Steel heated with an oxyacetylene flame becomes fluid between 2,450 and 2,750–F (1,343_ and l,510–C), depending on its composition. It passes through a soft range between the solid and liquid state. This soft range enables the operator to control the weld. To produce a weld with good fusion the welding rod should be placed in the molten puddle; then the rod and base metal should be melted together so that they will solidify to form a solid joint. Care should be taken to avoid heating a large portion of the joint, because this will dissipate the heat and may cause some of the weld metal to adhere to but not fuse with the sides of the welded joint. The flame should be so directed against the sides and bottom of the welded joint that complete penetration of the lower section of the joint is obtained. Weld metal should be added in sufficient quantities to fill the joint without leaving any undercut or overlap. Do not overheat because this will burn the weld metal and weaken the finished joint.

(3) Impurities.

(a) Oxygen, carbon, and nitrogen act to produce defective weld metal because they tend to increase porosity, blowholes, oxides, and slag inclusions.

(b) When oxygen combines with steel to form iron oxides at high temperatures, care should be taken to ensure that all the oxides formed are removed by proper manipulation of the rod and torch flame. An oxidizing flame (paragraph 6.6.2.1b(4)) causes the steel to foam and give off sparks. The oxides formed are distributed through the metal and cause a brittle, porous weld. Oxides that form on the surface of the finished weld can be removed by wire brushing after cooling.

(c) A carburizing flame (paragraph 6.6.2.1b(3)) adds carbon to the molten steel and causes boiling of the metal. Steel welds made with strongly carburizing flames are hard and brittle.

(d) Nitrogen from the atmosphere will combine with molten steel to form nitrides of iron, which impair its strength and ductility if included in sufficient quantities.

(e) By controlling the melting rate of the base metal and welding rod, the size of the puddle, the speed of welding, and the flame adjustment, the inclusion of impurities from the above sources may be held to a minimum.

c. Welding Steel Plates.

(1) In plates up to 3/16 inch in thickness, joints are prepared with a space between the edges equal to the plate thickness. This allows the flame and welding rod to penetrate to the root of the joint. Proper allowance should be made for expansion and contraction in order to eliminate warping of the plates or cracking of the weld. Figures 6-52 and 6-53 show edge preparation for different thicknesses of metal.

(2) The edges of heavy section steel plates (more than 3/16 inch thick) should be beveled (figure 6-52) to obtain full penetration of the weld metal and good fusion at the joint. Use the forehand method of welding (paragraph 6.6.5).

NOTE

Welding of plates 1/2 to 3/4 inch thick is not recommended for oxyacetylene welding.

(3) Plates 1/2 to 3/4 inch thick should be prepared for a U type joint (figure 6-52) in all cases. The back hand method (paragraph 6.6.6) is generally used in welding these plates.

(4) The edges of plates 3/4 inch or thicker are usually prepared by using the double V or double U type joint (figure 6-52) when welding can be done from both sides of the plate. A single V or single U joint is used for all plate thicknesses when welding is done from one side of the plate.

d. General Principles in Welding Steel.

(1) A well balanced neutral flame (paragraph 6.6.2.1b(2)) is used for welding most steels. To be sure that the flame is not oxidizing it is sometimes used with a slight acetylene feather. A very slight excess of acetylene may be used for welding alloys with a high carbon, chromium, or nickel content. However, increased welding speeds are possible by using a slightly reducing flame. Avoid excessive gas pressure because it gives a harsh flame, and makes molten metal control difficult.

(2) The tip size and volume of flame used should be sufficient to reduce the metal to a fully molten state and to produce complete joint penetration. Care should be taken to avoid the formation of molten metal drip beads from the bottom of the joint. The flame should bring the joint edges to the fusion point ahead of the puddle as the weld progresses.

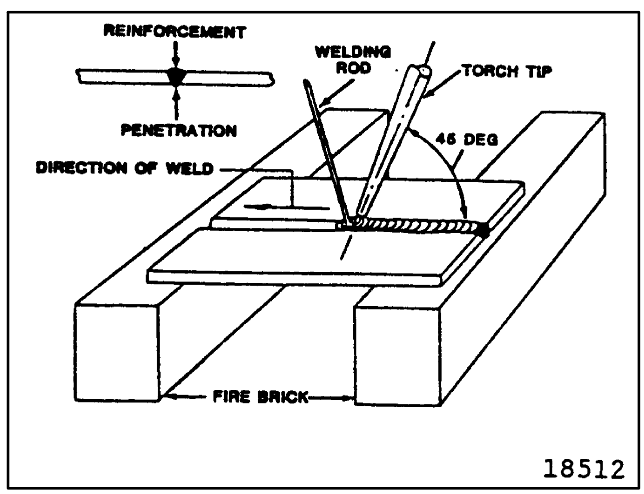


Figure 6-51. Position of Rod and Torch for a Butt Weld in a Flat Position

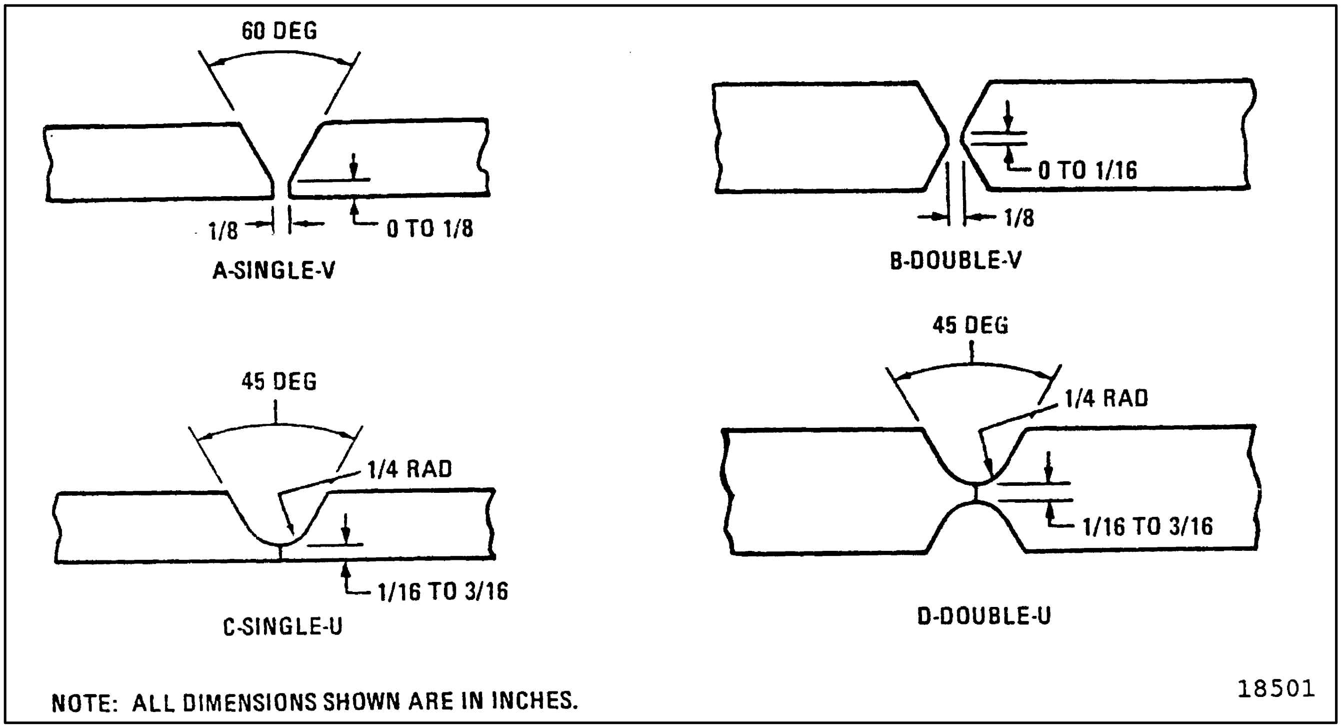


Figure 6–52. Butt Joints in Heavy Sections

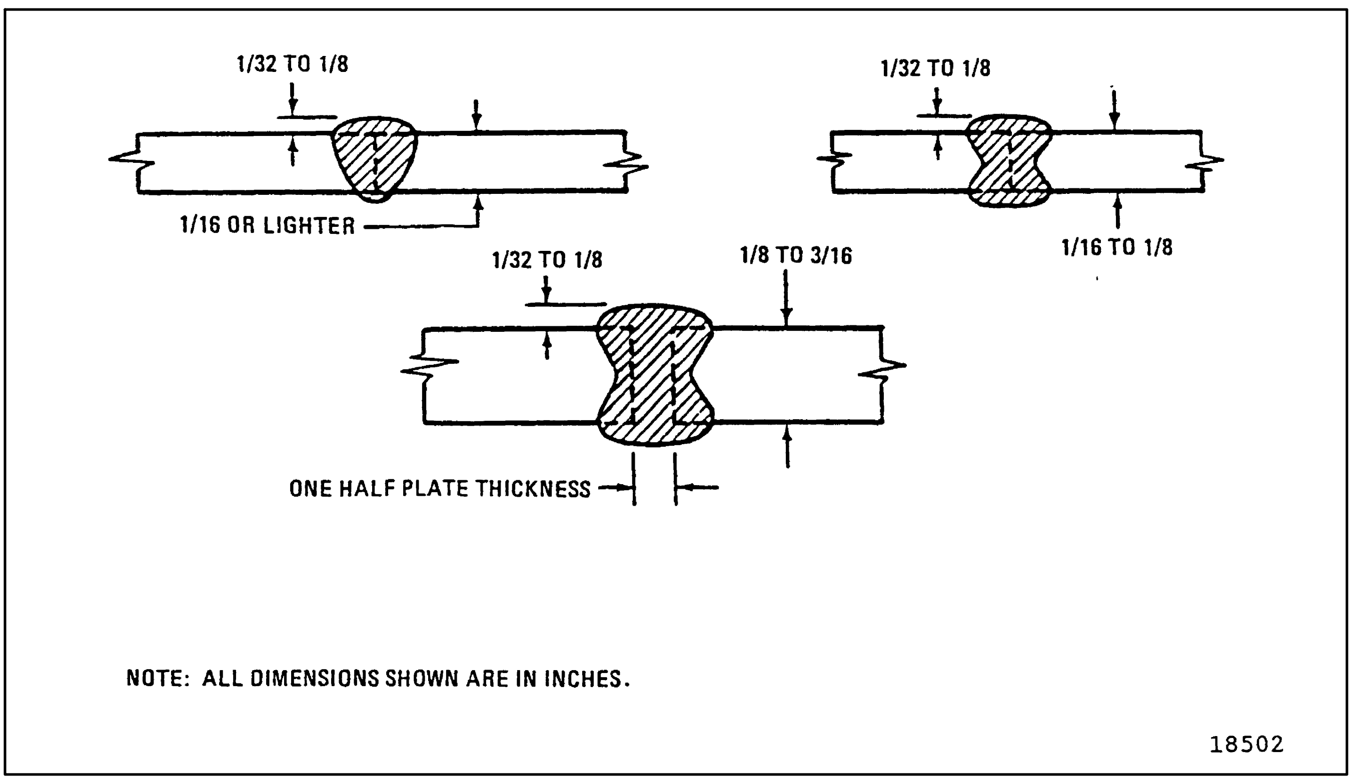


Figure 6–53. Butt Joints in Light Sections

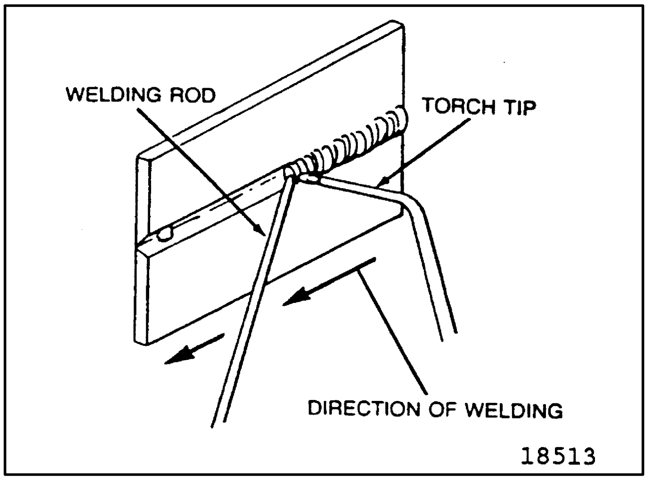


Figure 6-54. Welding a Butt Joint in the Horizontal Position

(3) The pool of the molten metal should progress evenly down the seam as the weld is being made.

(4) The inner cone tip of the flame should not be permitted to come in contact with the welding rod, molten puddle, or base metal. The flame should be manipulated so that the molten metal is protected from the atmosphere by the envelope or outer flame.

(5) The end of the welding rod should be melted by placing it in the puddle under the protection of the enveloping flame. The rod should not be melted above the puddle and allowed to drip into it.

6.7.2 <u>Low Carbon Steel</u>.

a. In general no difficulties are encountered in welding low carbon steels and the procedures prescribed in paragraph 6.2.4a for welding steels apply to these metals. Properly made low carbon steel welds will equal or exceed the base metal in strength.

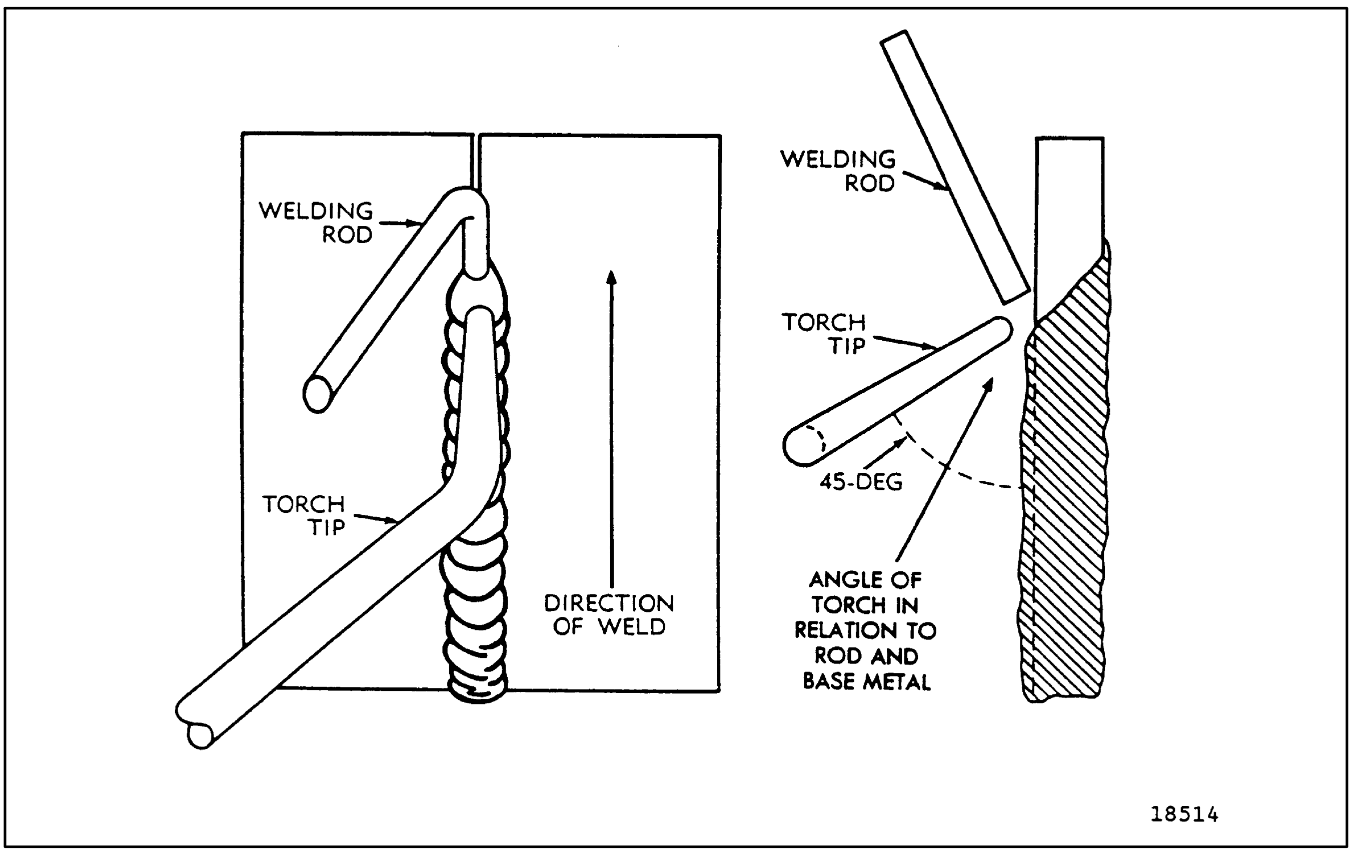


Figure 6-55. Welding a Butt Joint in the Vertical Position

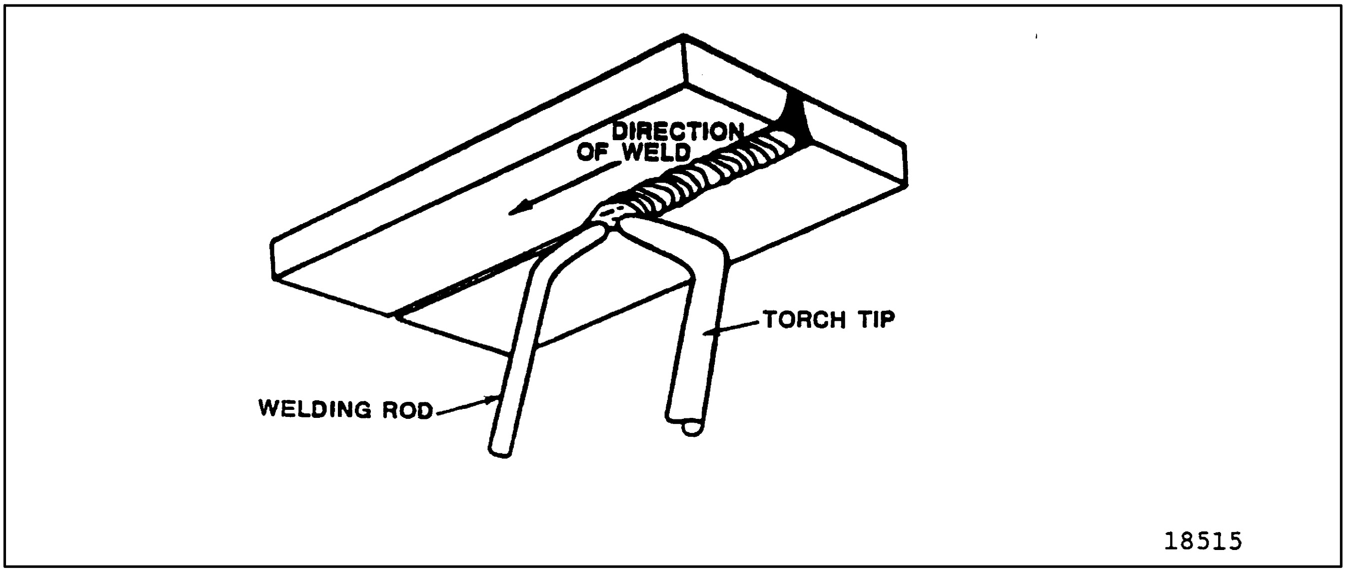


Figure 6–56. Welding a Butt Joint in the Overhead Position

NOTE

Rods from 5/l6 to 3/8 inch are available for heavy welding. However, heavy welds can be made with the 3/16 or l/4 inch rods by properly controlling the puddle and melting rate of the rod.

b. Copper coated low carbon rods should be used for welding low carbon steel. The rod sizes for various plate thicknesses are as follows:

Plate thickness, inch	Rod diameter inch
1/16 to 1/8	1/16
1/8 to 3/8	1/8
3/8 to 1/2	3/16
1/2 an heavier	1/4

c. The joints may be prepared by flame cutting or machining. The type of preparation (figure 6–52) will be determined by the plate thickness and the welding position.

d. No preheating, except to remove the chill from the plates, is required.

e. The flame should be adjusted to neutral. Either the forehand (paragraph 6.6.5) or backhand (paragraph 6.6.6) welding method may be used, depending on the thickness of the plates being welded.

f. Do not overheat the molten metal because this will cause the metal to boil and spark excessively. The resultant grain structure of the weld metal will be large, the strength will be lowered, and the weld will be badly scaled.

g. Low carbon steels do not harden in the fusion zone as a result of welding heat.

6.7.3 Chrome–Molybdenum Alloy Steels.

a. These steels may be welded satisfactorily by all methods and processes. The oxyacetylene flame is generally preferred for welding thin walled tubing and light gage sheet metal. For materials greater than 3/32 inch thick the electric arc is preferred because the heat zone will be narrower; and as a result the base metal will be less affected by the heat stresses. This is a special advantage where the part is too large to be heat treated to relieve welding stresses.

b. The welding technique with the oxyacetylene flame is about the same as that required for carbon steels. The area surrounding the weld should be preheated between 300− and 800−F (149− and 427−C), depending on the thickness of the metal. This is necessary because a sudden application of flame without preliminary heating might cause the formation of cracks in the heated area. The flame should be directed at the metal at such an angle that preheating takes place ahead of the weld.

c. A copper–coated low carbon welding rod is used for general welding of this metal with the oxyacetylene flame. Chrome–molybdenum or high strength rods may be used for joints requiring high strength. The strength of parts welded with these rods can be increased by heat treatment.

d. A neutral or slightly carburizing (paragraph 6.6.2.1b(2) and (3)) flame must always be used. An oxidizing flame burns and weakens the steel. A weld made with this flame may crack on cooling unless contraction is unrestrained. A highly carburizing flame makes the metal brittle and will cause cracking on cooling. The volume of flame should be just large enough to melt the base metal and to obtain good fusion.

e. Overheating the metal will set up severe stresses and cause excessive grain growth. This condition produces low strength in the weld and the adjacent base metal.

f. The weld should be protected from the air as much as possible to avoid scaling and rapid cooling. When available, a jet of hydrogen directed on the metal from the side opposite the weld will reduce scaling caused by oxidation, and will add strength to the finished part by eliminating air hardening around the weld.

g. When jigs or fixtures are used they should be designed to allow a maximum amount of movement to avoid distortion or cracking due to contraction as the metal cools.

6.7.4 Cast Iron.

a. Preheating. Cast iron should be preheated to a dull red heat (l,472_F (800_C) before welding to equalize expansion and contraction stresses. Heating of the entire casting is desirable, except for thin sections which are completely restrained. This preheating can be performed with an acetylene torch, a furnace heated by charcoal, oil or gas burners, or other available sources of heat. If the preheating is not uniform the finished weld will be warped and cracks may appear on the surface or in the weld metal. Preheating also helps to soften the casting because the carbon in the weld metal will separate as graphite. When the preheated metal is allowed to cool slowly the finished weld will have a minimum of cooling stresses, internal strains, and can be machined without difficulty. Slow cooling is achieved by covering the entire casting with suitable high temperature insulating material. If the casting is not cooled slowly after welding the weld area will be transformed into white cast iron. White cast iron is very brittle, difficult to machine, and may crack when the assembled part is used.

b. Preparation for Welding.

(1) Scale, cutting slag, grease, and dirt must be completely removed from the parts to be welded by grinding, wire brushing, sand– blasting, etc. Cracks in casting should be chipped out with a cold chisel to form a 90 degree V and should extend to approximately 1/8 inch from the bottom of the crack. A 120 degree V is sometimes desirable when the weld is made from one side only. A hole drilled at the extreme end or ends of a crack will prevent it from spreading during welding.

c. Welding Rod.

(1) The welding rod is cast iron with a melting point as low as practical. It must be free of nonmetallic inclusions and low in phosphorus and sulfur content.

d. Flux.

(1) Flux must be used in welding cast iron to remove the slag that forms on the cast iron puddle. The flux acts to clean the metal, remove slag inclusions, prevent porosity, and provide a sound weld. Fluxed welding rods are obtainable but usually the flux is applied by dipping the hot rod into the flux and transferring it to the molten puddle as required to overcome momentary difficulties.

e. Welding Method.

(1) The torch should be adjusted to give a neutral flame (paragraph 6.6.2.1b(2)). The flame should be pointed toward the finished weld (backhand welding) and the inner cone tip should be approximately 1/8 to 1/4 inch away from the molten puddle. A slight weaving motion should be used to melt down the sides and penetrate to the bottom of the V.

(2) In general the same precautions should be taken as in welding steel. The end of the welding rod should be heated, dipped into the flux, placed in the weld metal puddle, and gradually melted. The rod should not be held above the weld and melted drop by drop. Care should be taken that the sides of the bevel are completely melted and that the weld metal does not come in contact with cold base metal. The rod should be used to puddle out any slag, dirt, or blow– holes that may occur during welding.

(3) Care should be taken not to overheat the metal and thus cause the puddle to run away or burn through. The rod should be dipped into the flux often enough to insure fluidity of the weld metal. The preferred technique is to deposit the weld in layers not exceeding 1/8 inch thick, and to build the weld slightly above the level of the base metal to provide some reinforcement.

(4) Allowances should be made for expansion during heating and contraction while cooling, and the parts to be welded should be aligned in such a manner that the welded pieces assume the desired shape.

(5) Cast iron welding should be carried on as rapidly as possible. When the weld has been completed the entire piece should be reheated at a uniform rate (1,100_ to 1,500_F (593_ to 816_C)), and held at this temperature for 1 hour per inch of thickness; then cooled at a rate not to exceed 50_F (10_C) per hour. This process will relieve stresses and strains caused by welding. Cooling may be accomplished in the stress relieving furnace, or by covering the reheated piece with heat insulating material.

f. Localized preheating of large castings. When a section of a large casting to be welded is so located that the weld can be made without upsetting the entire casting, local preheating may be used. in welding large castings, sections of which vary in thickness, the preheating should be controlled so as not to overheat and warp the lighter sections.

g. Sealing Porous Cast Iron Welds.

(1) Welds in cast iron castings, such as cylinder blocks, must be free from pores, minute cracks, and other defects that will cause leakage. In order to ensure watertightness a sealing coat made of powdered sulfur and fine graphite powder may be used. This material is prepared by melting four to five parts of sulfur and adding one part of graphite. The graphite is thoroughly mixed with the melted sulfur. If the mixture should ignite it can be extinguished by smothering with Refraisal cloth or equivalent. (PIN C1554–96, Size 33 inch wide. Source: Materials Division of Hitco, 1600 West 135th Street, Gardena, California 90249.) The material is cast into long bars by pouring the mixture into the v of an angle iron section lined with cloth. The cast bar is removed when cold and the refraisal cloth is removed before the sealing material is applied to the weld.

(2) Welds made on cast iron castings should be coated with this sealing material while the weld is still hot. The end of the cast bar is rubbed onto the hot weld. A small portion will melt and form a thin film on the weld. This application will penetrate into the small pores and cracks providing an effective seal when cool. All surface scale, slag, and other foreign material must be brushed from the weld before the sealing material is applied. This sealing material can be applied to cold welds by careful heating of the weld with the oxyacetylene torch.

h. Hard Spots in Cast Iron Weld.

(1) Hard spots in a cast iron weld, often complained of by machinists finishing up a casting which has been welded, are caused by chilling portions of the weld by plunging a cold rod into the puddle of molten metal, or by allowing a part of the weld to suddenly become cool by removing the torch from it, or by failure to protect the hot weld from cool air drafts. The result is a greater percentage of combined carbon and less of graphite, hence small parts of the casting are hard white iron instead of soft gray iron.

(2) Hard spots may also be caused by the chilling effect of the metal surrounding the weld. The casting adjacent to the weld must be kept hot so that there will be no chilling action along the border of the weld between the weld metal and the metal of the casting; otherwise, there may be a hard area along this boundary which will cause trouble in machining and finishing the surface of the casting. If proper care is taken during cooling of the casting and if it is thoroughly protected during welding, there is no reason for having hard spots in any part of the weld or adjacent metal.

6.8 GENERAL BRAZING.

a. General.

(1) A group of welding processes in which the filler metal is a nonferrous metal or alloy with a melting point above 800_F (427_C), but lower than that of the metals to be joined. The filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction.

b. Torch Brazing.

(1) A process in which a gas flame produces the necessary heat.

c. Twin Carbon-Arc Brazing.

(1) A process in which an arc is maintained between two carbon electrodes to produce the necessary heat.

d. Furnace Brazing.

(1) A process in which a furnace produces the necessary heat.

e. Induction Brazing.

(1) A process in which heat is obtained from resistance of the work to the flow of induced electric current.

f. Dip Brazing.

(1) A process in which heat is obtained in a molten chemical or metal bath. The bath provides the filler metal.

g. Resistance Brazing.

(1) A process in which heat is obtained from resistance to the flow of electric current in a circuit of which the work is a part.

h. In brazing, a nonferrous filler rod, strip, or wire is used for repairing or joining cast iron, malleable iron, wrought iron, steel, copper, nickel, and high melting point brasses and bronzes. Some of these brasses and bronzes, however, melt at a temperature so near to that of the filler rod that fusion welding rather than brazing is required.

i. In brazing with the oxyacetylene torch the base metal parts are heated to the temperatures required for the melting and free flowing of the brazing alloy. Care should be taken not to overheat the base metal. One method for determining the correct temperature is to touch the joint with the filler rod, strip, or wire as the heating progresses. As soon as the temperature of the metal is high enough to melt the alloy, the rod, strip, or wire is brought under the flame to perform the operation.

j. Repairs on high carbon and tool steels should be made by brazing only in cases of an emergency, and where the lower strength and hardness of the filler metal are acceptable. Brazing should never be used where the part is subjected to temperatures higher than 630−F (343−C).

k. Material and Equipment Required.

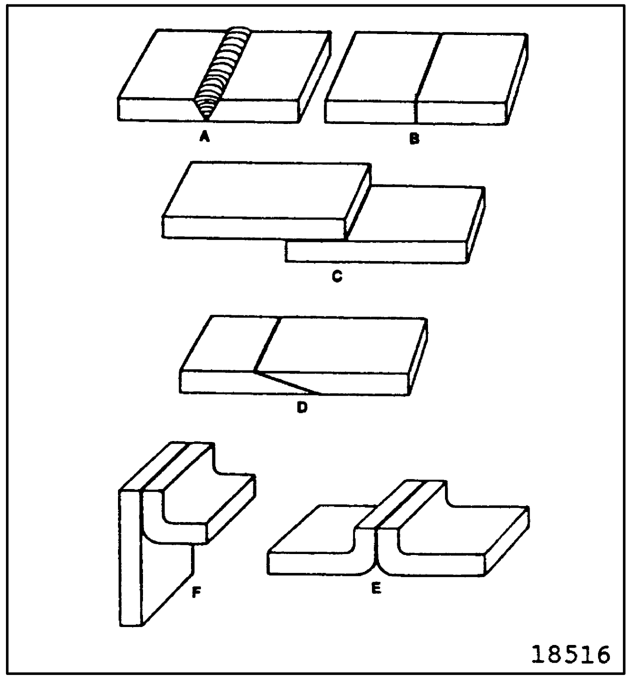


Figure 6-57. Joint Design

(1) Besides a welding torch with a proper tip size, a filler metal of the required composition and a proper flux are important to the success of any brazing operation.

(2) The choice of the filler metal depends on the types of metals to be joined. Copper-silicon (silicon-bronze) rods are used for brazing copper and copper alloys. Copper-tin (phosphorbronze) rods are used for brazing similar copper alloys and for brazing steel and cast iron. Other compositions are used for brazing specific metals.

(3) Fluxes are used to prevent oxidation of the filler metal and the base metal surface, and to promote the free flowing of the filler metal. They should be chemically active and fluid at the brazing temperature. After the joint members have been fitted and thoroughly cleaned, an even coating of flux should be brushed over the adjacent surfaces of the joint, taking care that no spots are left uncovered. The proper flux is a good temperature indicator for torch brazing because the joint should be heated until the flux remains fluid when the torch flame is momentarily removed.

l. Joint Design.

(1) The V groove joint (A, figure 6-57) is the proper design used for braze welding with copper base or bronze

welding rods, but it is not suitable for braze joints where the filler metal is distributed in the joint by capillary attraction.

WARNING

Dry cleaning solvent and mineral spirits paint thinner are highly flammable. Do not clean parts near an open flame or in a smoking area. Dry cleaning solvent and mineral spirits paint thinner evaporate quickly and have a defatting effect on the skin. When used without protective gloves, these chemicals may cause irritation or cracking of the skin. Cleaning operations should be performed only in well ventilated areas.

m. Preparation of Joint.

(1) The edges to be joined should be thoroughly cleaned of oxides by grinding or brushing. Surface dirt and grease should be washed away for a distance not less than one inch from each side of the joint with a grease solvent such as dry cleaning solvent or mineral spirits paint thinner. In brazing, galvanized coatings need not be removed. A flux paste applied for a distance of two inches on each side of the joint will prevent the galvanized coating from peeling or burning off. Parts to be joined should be aligned correctly and tack welded or clamped in the proper position.

n. Flame Adjustment.

(1) The flame should be slightly oxidizing, which will permit better bonding between the bronze and the base metal and suppress zinc fumes. The proper oxidizing flame is obtained by adjusting to neutral and then closing the acetylene valve slowly until the inner cone has been reduced in length by about one–tenth. In some cases the proper oxidizing flame is obtained after the operation is started by adjusting the acetylene valve until fuming ceases.

o. Tinning.

(1) Tinning is the spreading out of a thin layer of molten fluxed weld metal ahead of the main deposit to form a coating which provides a strong bond between the base metal and bronze. This tinning is due to the action of the flame and the flux. It will take place only when the base metal is at the right temperature. If the base metal is not hot enough the bronze will not flow; if too hot the molten bronze will boil, fume excessively, and will form droplets on the edges of the base metal. Proper tinning will be similar in appearance to water spreading over a clean moist surface, whereas improper tinning has the appearance of water on a greasy surface.

(2) A liberal amount of flux should be used, especially when the speed of brazing is rapid. This can be done by heating several inches of the end of the bronze rod and dipping or rolling it in a container of flux. Where brazing progresses more slowly, as in the repair of heavy castings, it is sufficient to dip the hot end of the rod into the flux, and add to the puddle as required.

p. Brazing Technique.

(1) Begin brazing by heating a small area just enough to cause the metal from the fluxed filler rod to spread out evenly and produce a tinning coat a short distance ahead of the main deposit. The inner cone of the slightly oxidizing flame should be kept 1/8 inch away from the surface of the metal. Usually the flame is pointed ahead of the completed bead at an angle of about 45 degrees, with the puddle under and slightly behind the flame. The torch angle may vary, depending on the position of the joint (overhead or vertical) and the thickness of the bead being made. The motion of the rod and torch will depend on the size of the puddle being carried, the nature of the joint or surfaces brazed, and the speed of brazing.

(2) When brazing heavy sections it may be necessary to deposit the filler metal in layers. In such cases the base metal must be thoroughly tinned when the first layer is deposited and care should be taken to ensure good fusion between layers.

(3) Never reheat the bead after it has solidified without adding more fluxed filler metal. Otherwise the deposited filler metal becomes porous and of low strength. Brazing should be done in one pass or layer whenever possible.

(4) Brazing, especially on castings, must be protected from drafts to permit slow cooling. This can be done by burying it in a box of lime or fine sand. No stress should be put on a bonded joint until it has cooled completely, because brass has a relatively low strength when hot.

(5) The finished bead should be cleaned with a wire brush to remove any excess flux from the surface of the metal.

6.8.1 Brazing Gray Cast Iron.

a. Gray cast iron can be brazed with very little or no preheating. For this reason, broken castings that would otherwise need to be dismantled and preheated can be brazed in place. A nonferrous filler metal such as naval brass (60 percent copper, 39.25 percent zinc, 0.75 percent tin) is satisfactory for this purpose. This melting point of the nonferrous filler metal is several hundred degrees lower than the cast iron; consequently the work can be accomplished with a lower heat input, the deposition of metal is greater and the brazing can be accomplished faster. Because of the lower heat required for brazing, the thermal stresses developed are less severe and stress relief heat treatment is usually not required.

b. The preparation of large castings for brazing is much like that required for welding with cast iron rods. The joint to be brazed must be clean and the part must be sufficiently warm to prevent chilling of filler metal before sufficient penetration and bonding are obtained. When possible the joint should be brazed from both sides to ensure uniform strength throughout the weld. In heavy sections the edges should be beveled to form a 60 to 90 degree V.

6.8.1.1 Brazing Malleable Iron. Malleable iron castings are usually repaired by brazing because the heat required for fusion welding will destroy the properties of malleable iron. Because of the special heat treatment required to develop malleability, it would be impossible to restore completely these properties by simply annealing. Where special heat treatment can be performed, welding with a cast iron filler rod and remalleabilizing are feasible.

6.8.2 Welding, Brazing, and Soldering Nonferrous Metals.

6.8.2.1 Copper Welding.

a. Copper has a high thermal conductivity; consequently the heat required for welding is approximately twice that required for steel of similar thickness. To offset this loss of heat a tip one or two sizes larger than that required for steel is recommended. When welding large sections of heavy thicknesses, supplementary heating with a charcoal fire, a separate heating unit, or another torch is advisable. This makes a weld that is less porous that one made by preheating and welding with the same torch.

b. Copper may be welded with a slightly oxidizing flame because the molten metal is protected by the oxide which is formed by the flame. If a flux is used to protect the molten metal the flame should be neutral.

c. Oxygen free copper (deoxidized copper rod) rather than oxygen bearing copper should be used for gas welded assemblies and the welding rod should be of the same composition as the base metal.

d. In welding copper sheets the heat is conducted away from the welding zone so rapidly that it is difficult to bring the temperature up to the fusion point. It is often necessary to raise the temperature level of the sheet in a large area, 6 inches to a foot away from the weld, nearly to red heat before a welding torch of the usual size is effective in welding the edges. The weld should be started at some point away from the end of the joint and welded back to the end with filler metal being added. Then, after returning to the starting point, the weld should be started and made in the opposite direction to the other end of the seam. During the operation the torch should be held at approximately a 60 degree angle to the base metal.

e. It is advisable to back up the seam on the underside with carbon blocks or thin sheet metal to prevent uneven penetration. These materials should be channeled or undercut to permit complete fusion to the base of the joint. The metal on each side of the weld should be covered with fire resistant material to prevent radiation of heat into the atmosphere, allowing the molten metal in the weld to solidify and cool slowly.

f. The welding speed should be uniform and the end of the filler rod should be kept in the molten puddle. During the entire welding operation the molten metal must be protected by the outer flame envelope. If the metal fails to flow freely during the operation the rod should be raised and the base metal heated to a red heat along the seam. The weld should be started again and continued until the seam weld is completed.

g. In welding thin sheets the forehand welding method is preferred, while the backhand method is preferred for thicknesses of 1/4 inch or more. For sheets up to 1/8 inch thick a plain butt joint with squared edges is preferred. For thicknesses greater than 1/8 inch the edges should be beveled for an included angle of 60 to 90 degrees, in order to obtain penetration without spreading fusion over a wide area.

6.8.2.2 Copper Brazing.

a. Both oxygen bearing and oxygen free copper can be brazed to produce a joint with satisfactory properties. The full strength of an annealed copper brazed joint will be developed with a lap joint (C, figure 6–57).

b. The flame used should be slightly carburizing. All of the silver brazing alloys can be used with the proper fluxes. With the copper–phosphorous or copper–phosphorous–silver alloys a brazed joint can be made without a flux, although the use of flux will result in a joint of better appearance.

c. Butt, lap, and scarf joints are used in brazing operations, whether the joint members are flat, round, tubular, or of irregular cross sections. Clearances to permit the penetration of the filler metal, except in large diameter pipe joints, should not be more than 0.002 to 0.003 inch. The clearances of large diameter pipe joints, may be 0.008 to 0.010 inch. The correct method of making a butt joint with brazing alloys is shown at B, figure 6–57; a lap joint is shown at C, figure 6–57. The joint may be made with inserts of the filler metal or the filler metal may be fed in from the outside after the joint has been brought up to the proper temperature. The scarf joint shown in D, figure 6–57, is used in joining band–saw blades and for joints where the double thickness of the lap is not desired. The joints E and F, figure 6–57, have advantages common to all lap joints.

6.8.2.3 Lead Welding.

a. General.

(1) The welding of lead is similar to welding of other metals except that no flux is required and processes other than gas welding are not in general use.

b. Gases Used.

(1) Three combinations of gases are commonly used for lead welding. These are oxyacetylene, oxy–hydrogen, and oxygen–natural gas. The oxyacetylene and oxy–hydrogen processes are satisfactory for all positions. The oxygen–natural gas is not used for overhead welding. A low gas pressure ranging from 1 1/2 to 5 psi is generally used, depending on the type of weld to be made.

c. Torch.

(1) The welding torch is relatively small in size, with the oxygen and flammable gas valves located at the forward end of the handle so that they may be conveniently adjusted by the thumb of the holding hand. Torch tips range in drill size from 78 to 68. The smaller tips are for 6–pound lead (i.e. 6 pounds per sq. ft.), the larger tips for heavier lead.

d. Welding Rods.

(1) The filler rods should be of the same composition as the lead to be welded. They range in size from 1/8 to 3/4 inch in diameter. The smaller sizes are used for lightweight lead and the larger sizes for heavier lead.

e. Types of Joints.

(1) Butt, lap, and edge joints are the types most commonly used in lead welding. Either the butt or lap joint is used on flat position welding. On vertical and overhead position welding the lap joint is used. The edge or flange joint is used only under special conditions.

f. Welding Technique.

(1) The flame must be neutral. A reducing flame will leave soot on the joint and an oxidizing flame will produce oxides on the molten lead and will produce coalescence. A soft, bushy flame is most desirable for welding in a horizontal position. A more pointed flame is generally used in the vertical and overhead positions.

(2) The flow of molten lead is controlled by the flame, which is usually handled with a semicircular or V–shaped motion. This accounts for the herringbone appearance of the lead weld. The direction of the weld depends on the type of joint and the position of the weld. The welding of vertical position lap joints is started at the bottom of the joint. A welding rod is not generally used. In flat position welding lap joints are preferred. The torch is moved in a semicircular path toward the lap and then away. Filler metal is used but not on the first pass. Overhead position welding is very difficult. For that position a lap joint and a flame as sharp as possible are used. The molten beads must be small and the welding operation must be completed quickly.

6.8.2.4 Silver Brazing.

a. Silver brazing, frequently called ”silver soldering,” is a low temperature brazing process with rods having melting points ranging from 1,145_ to 1,650_F (618_ to 899_C). This is considerably lower than that of the copper alloy brazing filler metals. The strength of a joint made by this process is dependent on a thin film of silver brazing filler metal.

b. Silver brazing filler metals are composed of silver with varying percentages of copper, nickel, tin, and zinc. They are used for joining all ferrous and nonferrous metals except aluminum, magnesium, and other metals which have too low a melting point.

c. It is essential that the joints be free of oxides, scale, grease, dirt, or other foreign matter. Surfaces other than cadmium plating can be easily cleaned mechanically by wire brushing, or an abrasive cloth; chemically by acid pickling or other means. Extreme care must be used in grinding all cadmium surfaces to the base metals since cadmium oxide fumes formed by heating and melting of silver brazing alloys are highly toxic.

d. Silver braze flux is generally required. The melting point of the flux must be lower than the melting point of the silver brazing filler metal so that it will clean the base metal and properly flux the molten metal. A satisfactory flux should be applied by means of a brush to the parts to be joined and also to the silver brazing filler metal rod.

e. When silver brazing by the oxyacetylene process, a strongly reducing flame is desirable. The outer envelope of the flame, not the inner cone, should be applied to the work. The cone of the flame is too hot for this purpose. Joint clearances should be between 0.002 and 0.005 inch for best filler metal distribution. A thin film of filler metal in a joint is stronger and more effective, and a fillet build up around the joint will increase its strength. Some joints which can be used are shown in figure 6–58.

f. The base metal should be heated until the flux starts to melt along the line of the joint; the filler metal is not subjected to the flame but is applied to the heated area of the base metal just long enough to flow the filler metal completely into the joint. If one of the parts to be joined is heavier than the other, the heavier part should receive the most heat. Also, parts having high heat conductivity should receive more heat

6.8.2.5 Cutting with Oxyacetylene Flame.

a. General.

(1) If iron or steel is heated to its kindling temperature (not less than l,600_F, (871_C)), and then brought into contact with oxygen it burns or oxidizes very rapidly. The reaction of oxygen with the iron or steel forms iron oxide ($Fe_3 0_4$) and gives off considerable heat. This heat is sufficient to melt the oxide and some of the base metal; consequently, more of the metal is exposed to the oxygen stream. This reaction of oxygen and iron is used in the oxyacetylene cutting process. A stream of oxygen is firmly fixed onto the metal surface after it has been heated to the kindling temperature. The hot metal reacts with oxygen, generating more heat and melting. The molten metal and oxide are swept away by the rapidly moving stream of oxygen. The oxidation reaction continues and furnishes heat for melting another layer of metal. The cut progresses in this manner. The principle of the cutting process is shown in Figure 6–59.

(2) Theoretically, the heat created by the burning iron would be sufficient to heat adjacent iron red hot, so that once started the cut could be continued indefinitely with oxygen only, as is done with the oxygen lance. In practice, however, excessive heat absorption at the surface caused by dirt, scale, or other substances, makes it necessary to keep the preheating flames of the torch burning throughout the operation.

6.9 CUTTING STEEL AND CAST IRON

a. General.

(1) Plain carbon steels with a carbon content not exceeding 0.25 percent can be cut without special precautions other than those required to obtain cuts of good quality. Certain steel alloys develop high resistance to the action of the cutting oxygen, making it difficult and sometimes impossible to propagate the cut without the use of special techniques.

6.10 SCARFING, GOUGING AND HOGGING.

a. General.

(1) This portion includes those processes where oxygen and an oxyacetylene flame are used in removing the surfaces of metals. Several of these processes are described below.

(2) Scarfing or Deseaming.

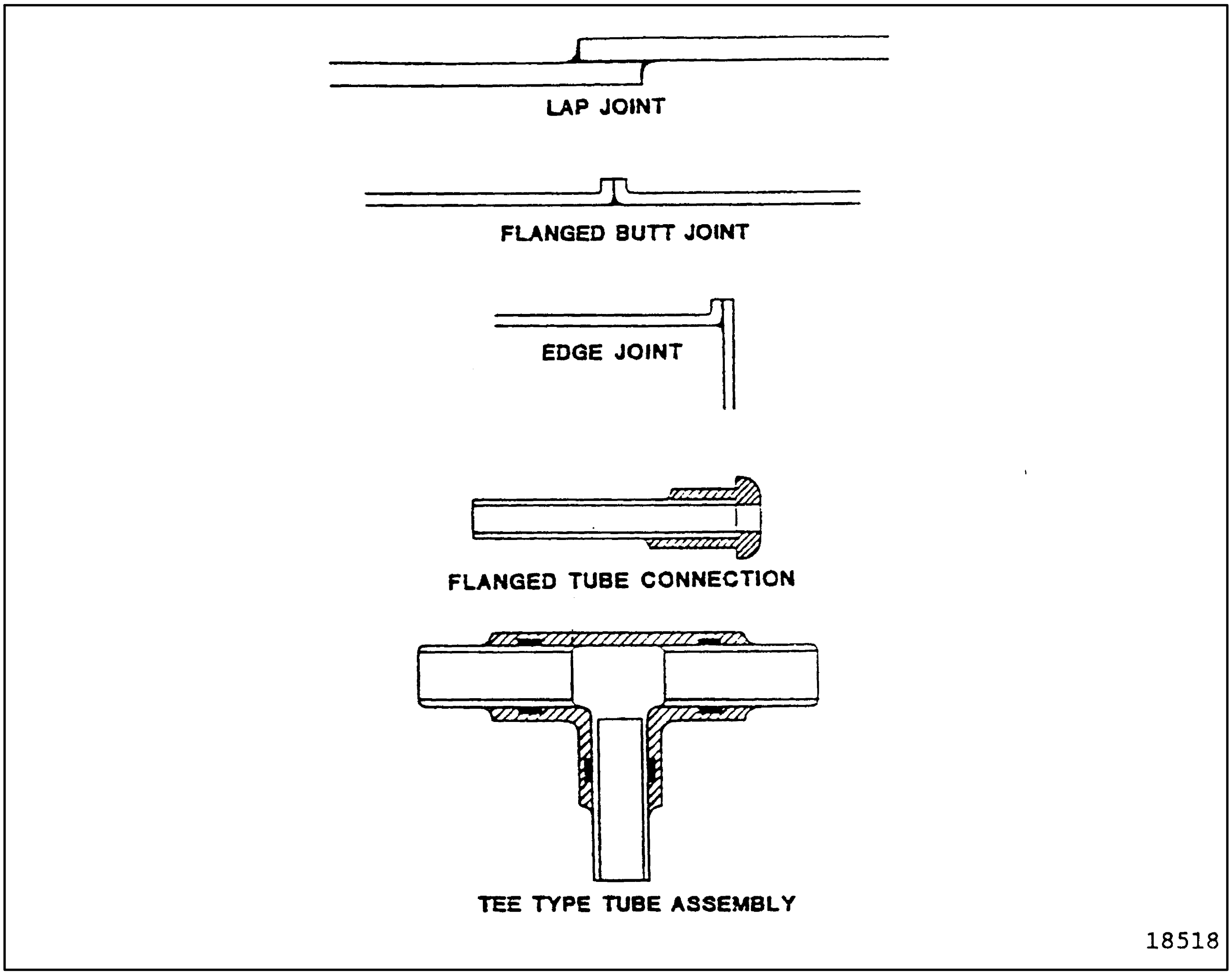


Figure 6–58. Silver Brazing Joints

(a) This process is used for the removal of cracks, scale, and other defects from the surface of blooms, billets, and other unfinished shapes in steel mills. In this process, a spot or area on the surface of the metal is heated to the ignition temperature, then a jet or jets of oxygen are impinged on the preheated area and advanced as the surface is cut away. The scarfed surface is comparable to that of steel cleaned by chipping.

(3) Gouging.

(a) This process is used for the removal of welds. It is also used in the elimination of defects such as cracks, sand inclusions, and porosity from steel castings.

(4) Hogging.

(a) This is a flame machining process used for the removal of excess metals such as risers and sprues from castings. It is a combination of scarfing and gouging techniques.

6.11 PLASMA ARC CUTTING (PAC).

a. General.

(1) A plasma is a mixture of free electrons, positively charged ions and neutral atoms. The plasma is formed in the torch head by swirling a gas (often air in cutting operations) around a tungsten electrode in a small arc chamber. The gas is

ionized to a plasma, expands and accelerates through a nozzle or orifice which constricts the flow to form a high energy jet of plasma. The jet heats the work piece by bombarding it with electrons and transferred energy from the high temperature gas. Cutting power depends upon intensity and velocity of the plasma which is controlled by gas composition, inlet pressure and the shape and size of the nozzle orifice. The process may be used for almost any metal which conducts electricity.

6.11.1 Safety Cautions.

6.11.1.1 Eye Protection.

a. Wear dark safety glasses or goggles with side shields or a welding helmet to protect eyes against plasma arc's Ultraviolet (UV) and Infrared (IR) rays.

ARC CURRENT	Lens Shade (AWS #)
up to 100 Amps.	No. 8
100 – 200 Amps	No. 10
200 – 400 Amps.	No. 12
Over 400 Amps	No. 14

b. Replace the glasses, goggles or helmet when the lens becomes pitted or broken.

c. Warn other people in the area not to look directly at the arc unless they are wearing glasses, goggles or a helmet.

d. Prepare the cutting area in a manner that reduces the reflection and transmission of UV light.

(1) Paint walls and other surfaces with dark colors to reduce reflection.

(2) Install protective screens or curtains to reduce UV transmission.

6.11.1.2 Skin Protection.

a. Wear protective clothing to protect against burns caused by UV, sparks or hot metal.

(1) Gauntlet gloves, safety shoes and hat.

(2) Flame–retardant clothing which covers all exposed areas.

(3) Cuffless trousers to prevent entry of sparks and slag.

6.11.1.3 Noise Prevention

a. The plasma cutting process can generate high levels of noise. Always wear proper ear protection when cutting or gouging with the plasma system.

6.11.1.4 Toxic Fume prevention.

a. Keep the cutting area well ventilated.

b. Remove all chlorinated solvents from the cutting area before cutting. Certain chlorinated solvents decompose when exposed to UV radiation to form phosgene gas.

c. Wear proper breathing mask and use proper ventilation when cutting galvanized metal.

d. Do not cut containers that have had toxic materials inside. Clean containers that have held toxic materials thoroughly before cutting.

WARNING

Do not cut metal or painted metals containing zinc, lead, cadmium or beryllium unless the operator, or anyone else subjected to the fumes, wears respiratory equipment or an air supplied helmet.

6.11.1.5 Fire Prevention.

a. Make fire extinguishers available in the cutting area.

b. Remove combustible material from the immediate cutting area to a distance of at least 35 ft.

c. Quench freshly cut metal or allow metal to cool before handling it or bringing it into contact with combustible materials.

d. Never use plasma system to cut containers with potentially flammable materials inside. Such containers must be thoroughly cleaned prior to cutting.

e. Ventilate potentially flammable atmospheres before cutting with a plasma system. When cutting with oxygen as the plasma gas, an exhaust ventilation system is required.

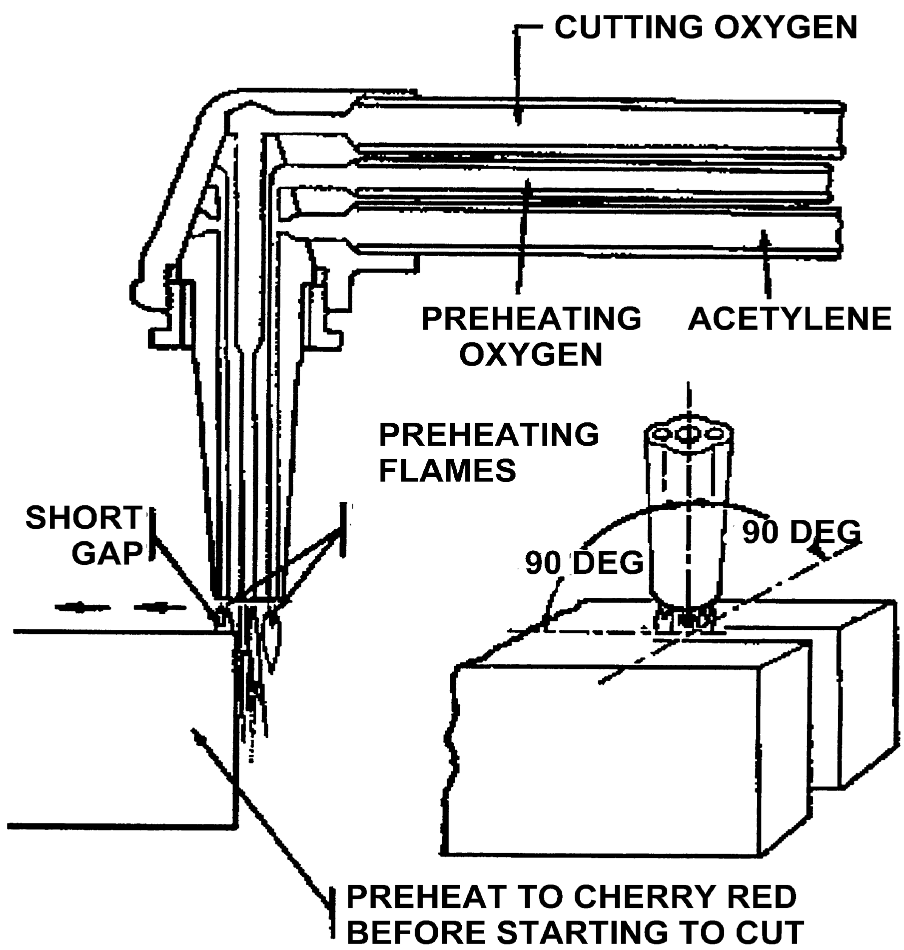


Figure 6-59. Starting a Cut and Cutting with a Cutting Torch

f. Never operate the plasma system in an atmosphere which contains heavy concentrations of dust, flammable gas or combustible liquid vapors unless properly vented.

6.11.1.6 Electric shock prevention

a. Wear insulated gloves and boots and keep body and clothing dry.

b. Do not stand, sit, touch or lie on any wet surface when using the plasma system.

c. Inspect the primary power cord frequently for damage or cracking of the cover. Bare wiring can kill. Do not use a system with a damaged power cord. Replace a damaged power cord immediately.

d. Inspect the torch lead. Replace if frayed or damaged.

e. Do not pick up the work piece, including the waste cutoff while cutting. Leave the work piece in place or on the workbench with the work cable attached during the cutting process.

f. Before changing the torch parts disconnect the main power or unplug the power supply. After changing torch parts and replacing the retaining cap, plug in the power supply again.

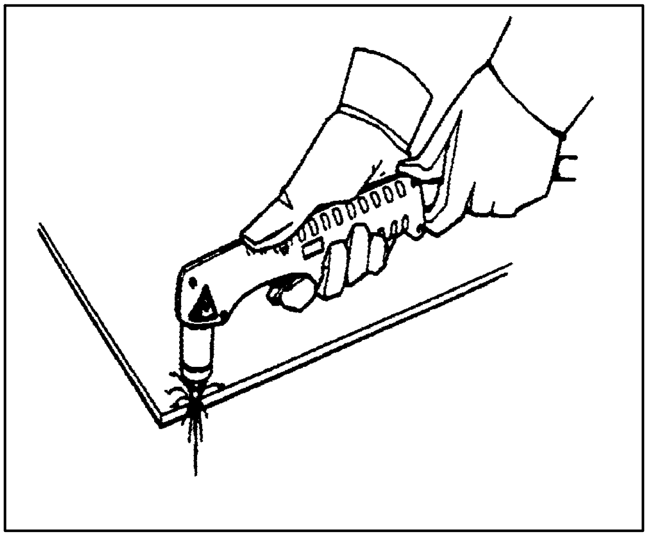


Figure 6-60. Starting a Cut

g. Before removing a power supply cover for maintenance disconnect the main power at the wall disconnect switch or unplug the power supply. To avoid exposure to severe electrical hazard wait five minutes after disconnecting the main power to allow capacitors to discharge.

6.11.1.7 Grounding

a. Be sure to connect the power cord ground wire to the ground in the disconnect box.

b. Tighten all electrical connections to avoid excessive heating.

c. Attach the work cable securely to the work piece or the work table by making good metal to metal contact as close as possible to the area to be cut. Do not connect it to the piece that will fall away when the cut is complete.

d. Connect the work table to a high-quality ground.

6.11.1.8 Cutting Operations

a. The plasma inverter produces DC output voltage and cutting occurs in a transferred arc mode. The circuit must be complete. Ensure good metal to metal contact of work clamp as close as possible to area to be cut.

b. Start at the edge of the work piece. (Refer to Figure 6-60).

c. Sparks should come out of the bottom. If spraying on top, the torch is moving too fast, or there is not sufficient power to fully penetrate the work piece. (Refer to Figure 6-61 and Table 6-10.)

d. Hold the torch lightly on the metal or just off the metal. Holding the torch firmly to the work piece causes the shield or nozzle to stick and makes smooth cutting difficult. The arc transfers to the work piece once the torch is within 1/8 inch of the surface.

e. Pulling the torch through the cut is easier than pushing it.

f. Hold the torch nozzle at a vertical position and watch the arc as it cuts along the line. By lightly dragging the shield or nozzle on the work piece, it is possible to maintain a steady cut. (Refer to figure 6-61).

g. When cutting thin material reduce amperage until the best quality cut is obtained. (Refer to Table 6-10 for cutting amperages.)

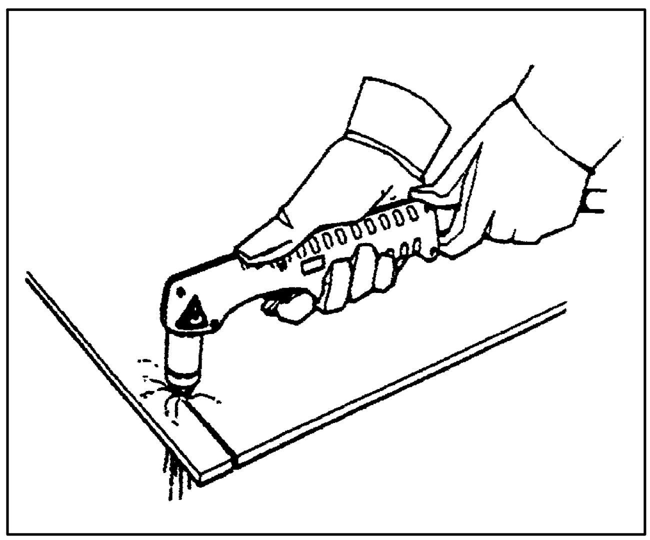


Figure 6-61. Dragging the Torch

Table 6–10. Cutting Amperages

Material Thickness		Material	Arc Current	Arc Voltage	Recommended Travel Speed*		Pierce Delay
	(mm)		(A)	(V)	(ipm)	(mm/min)	(S)
24 ga	0.6	Mild Steel	20	113	200	5080	–
20 ga.	0.8	Mild Steel	20	114	144	3660	–
18 ga.	1.2	Mild Steel	20	115	86	2180	–
16 ga.	1.5	Mild Steel	20	116	46	1170	–
16 ga.	1.5	Mild Steel	30	109	110	2790	–
14 ga.	2	Mild Steel	30	110	65	1650	–
12 ga.	2.7	Mild Steel	30	112	45	1140	–
10 ga.	3.4	Mild Steel	30	116	28	710	0.5
3/16”	4.8	Mild Steel	30	123	23	580	1.0
1/4”	6.4	Mild Steel	30	126	18	460	2.0
1/32”	.8	Aluminum	30	105	260	6600	–
1/16”	1.5	Aluminum	40	105	200	5080	–
3/32”	2.4	Aluminum	40	105	192	4880	–

* Recommended travel speeds are 10–20% slower than maximum. These slower speeds will produce optimum cut quality.

SECTION VII.
POSTWELDING

7.1 POSTWELDING.

Probably the single most important method of inspection is visual examination. Visual examination here is defined as examination using the naked eye, alone or in conjunction with various magnifying devices, without changing, altering, or destroying the materials involved.

7.1.1 Inspection Procedure. The finished weld should be inspected for undercut, overlap, surface checks, cracks, or other defects. Also, the degree of penetration and side wall fusion, extent of reinforcement, and size and position of the welds are important factors in the determination as to whether a welding job should be accepted or rejected because they all reflect the quality of the weld.

7.2 POSTHEATING OF STEEL.

Generally, postheating is specified for the steels in table 7–1 that contain more than about 0.35% C, although there are many exceptions.

7.2.1 Stress relieving usually is required and may be mandatory for weldments of all of the steels listed in table 7–1, if the weldment is to be put into service without being quenched and tempered. If a weldment is to be quenched and tempered, stress relieving can usually be omitted. Dimensional stability and notch toughness usually determine the need for stress relief.

7.2.2 In preferred practice, the heating for stress relieving, or for the austenitizing that precedes quenching, should begin before the weldment cools to a temperature below the interpass temperature. However, this procedure is not always practical, and in some applications the weldment remains at room temperature for an indefinite time before being stress relieved. Drafts of air impinging on the weldment while it is cooling to room temperature should be avoided.

Table 7–1. Suggested Preheat And Interpass Temperatures For Various Alloy Bar Steels

	Preheat and Interpass Temperature, −F For Section Thickness of:		
Steel	To 1/2 inch	1/2 to 1 inch	1 to 2 inch
1330	350–450	400–500	450–550
1340	400–500	500–600	600–700
4023	100 min	200–300	250–350
4028	200–300	250–350	400–500
4047	400–500	450–550	500–600
4118	200–300	350–450	400–500
4130	300–400	400–500	450–550
4140	400–500	600–700	600–700
4150	600–700	600–700	600–700
4320	200–300	350–450	400–500
4340	600–700	600–700	600–700
4620	100 min	200–300	250–350
4640	350–450	400–500	450–550
5120	100 min	200–300	250–350
5145	400–500	450–550	500–600
8620	100 min	200–300	250–350
8630	200–300	250–350	400–500
8640	350–450	400–500	450–550

7.2.3 For complete, or almost complete, stress relief, the weldment should be heated to 1100− to 1250−F and held for one hour per inch of maximum base–metal thickness. If heating in this range is impractical, partial stress relief can be attained by heating at a lower temperature (for instance, 900−F) for several hours.

7.2.4 Stress Relief of Magnesium. All stress relief of magnesium weldments shall be done in a furnace. Gas torch heating is prohibited. Temperature and time shall be as specified in table 7–2. Parts shall be cooled in still air.

7.3 SHOT–PEENING AFTER WELD.

a. The heat–affected areas adjacent to a weld are nearly always in tension, which can decrease the fatigue life of the welded assembly. Shot–peening, by inducing a compressive stress in the surface can substantially increase the fatigue life of welded assemblies.

b. Even on static applications such as pressure vessels, tanks and piping, the peening of welds has been found very beneficial.

c. In shot–peening, the surface of the finished part is bombarded with round steel shot in special machines under full–controlled conditions. Every piece of shot acts as a tiny peening hammer. When the surface has been peened all over by the multitude of impacts, the resultant residually stressed surface layer, which is in compression, prevents the formation of cracks.

d. It is well known that a crack will not propagate into a compressed layer. As nearly all fatigue and stress corrosion failures originate at the surface of a part, the layer of compressive stress induced by shot–peening produce the tremendous increase in life which many industries have learned to use in their designs. The maximum compressive residual stress produced at or near the surface is at least as great as half the ultimate tensile strength of the material.

e. Shot–peening is used to eliminate failures of existing designs, or to allow the use of higher stress levels, which, in turn, permit weight reduction for new designs.

f. The object of controlled shot–peening is to produce a compressively stressed surface layer in which the amount of stress, the uniformity of the stress, and the depth of the layer can be held constant from piece to piece. As it is practically impossible to inspect the stress distribution on a finished part, the full control of all aspects of the process becomes imperative. The basic variables of stress, depth, and coverage are obtained in practice by the use of the right combinations of shot, exposure time, choice of air pressure or wheel speed, nozzle size, distance of nozzle from part, and angle between shot stream and peened surface. It is extremely important that the relative motion between shot stream and part be mechanized for uniformity and reproducibility.

Table 7–2. Stress Relief Temperatures and Hold Time

Form	Alloy	Condition	Temperature Degrees	Time (Minimum)
All	All	“O” (Annealed) “F” (As Fabricated) “H” (Strain Hardened)	500− + l0− 350− + l0−F	15 minutes 60 minutes

APPENDIX A

WELDING SYMBOLS AND CODES

A.1. GENERAL. Welding symbols provide the means for placing complete and concise welding information on drawings. The reference line of the welding symbol is used to designate the type of weld to be made, its location, dimensions, extent, contour, other supplementary in formation, and when necessary a tail is attached to the reference line which provides specific notations. When such notations are not required the tail is omitted.

A.2. ELEMENTS OF A WELDING SYMBOL. A distinction is made between the term ”weld symbol” and ”welding symbol”. The ”weld symbol” is the ideograph that is used to indicate the desired type of weld. The assembled ”welding symbol” consists of the following eight elements or any of these elements as are necessary: reference line; arrow; basic weld symbols; dimensions and other data; supplementary symbols; finish symbols; tail; and the specification, process, or other reference. The location of the elements of a welding symbol with respect to each other is shown in figure A–1.

A.3. BASIC WELD SYMBOLS.

a. General. Weld symbols are used to indicate the following: welding processes used in metal joining operations; whether the weld is localized or ”all around;” shop or field welds; and the contour of the welds. These basic weld symbols are summarized in figure A–1 through figure A–4.

b. Arc and Gas Weld Symbols. These symbols shall be as shown in figure A–4.

c. Resistance Weld Symbols. The symbols shall be as shown in figure A–4.

d. Brazing, Forge, Thermit, Induction, and Flow Weld Symbols. These welds shall be indicated by using a process or specification reference in the tail of the welding symbols. When the use of a definite process is required the process may be indicated by one or more of the letter designations as shown in Table A–1. When no specification, process or other reference is used with a welding symbol, the tail may be omitted.

e. Supplementary Symbols. These symbols are used in many welding processes and shall be used as shown in figure A–2.

A.4. Location Significance of Arrow.

a. In fillet, groove, flange, and flash or upset welding symbols, the arrow shall connect the welding symbol reference line to one side of the joint, and this side shall be considered the ”arrow side” of the joint (A, figure A–3). The opposite side of the joint shall be considered the ”other side” of the joint (B, figure A–3).

b. In plug, slot, arc spot, arc seam, resistance spot, resistance seam and projection welding symbols the arrow shall connect the welding symbol reference line to the outer surface of one of the members of the joint at the center line of the desired weld. The member to which the arrow points shall be considered the ”arrow side” member. The other member of the joint shall be considered the ”other side” member.

c. When a joint is depicted by a single line on the drawing and the arrow of a welding symbol is directed to this line, the ”arrow side” of the joint shall be considered as the near side of the joint in accordance with the usual conventions of drafting (C and D, figure A–3).

d. When a joint is depicted as an area parallel to the place of projection in a drawing and the arrow of a welding symbol is directed to that area, the ”arrow side” member of the joint shall be considered as the near member of the joint in accordance with the usual conventions of drafting.

A.5. Location of the Weld With Respect to Joint. (See figure A–4.)

a. Welds on the arrow side of the joint shall be shown by placing the weld symbol on the side of the reference line toward the reader.

b. Welds on the other side of the joint shall be shown by placing the welding symbol on the side of the reference line away from the reader.

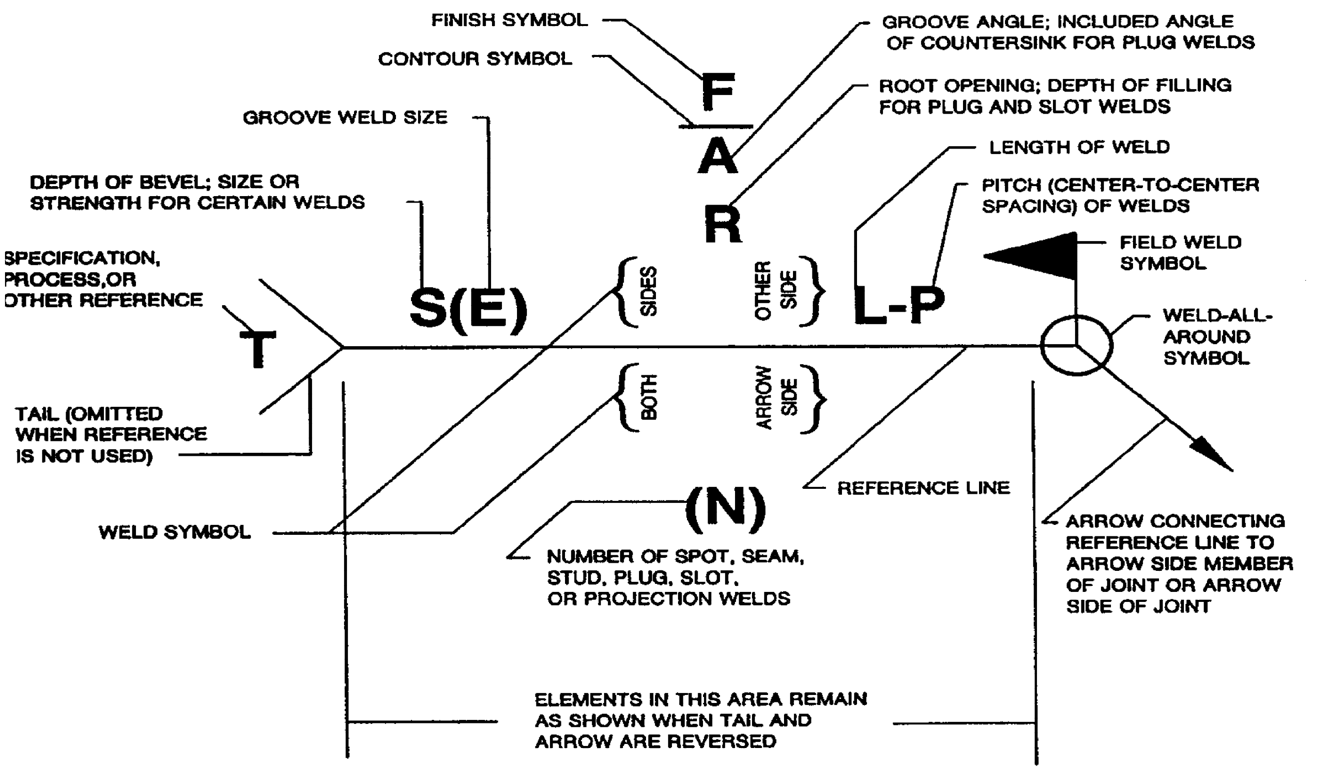


Figure A–1. Standard Location of Elements of a Welding Symbol

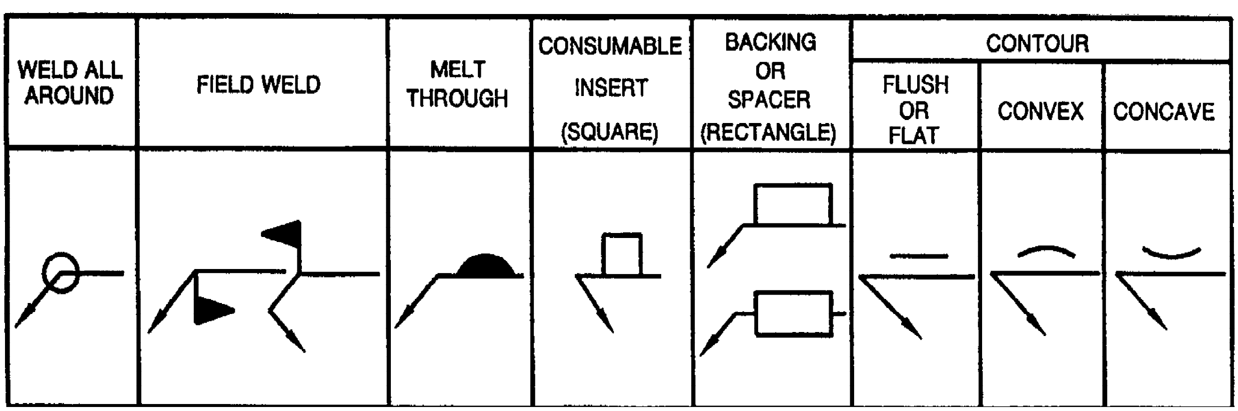


Figure A–2. Supplementary Symbols

Table A–1. Designation of Welding Processes by Letters

Brazing	B
Torch brazing	TB
Twin carbon–arc brazing	TCAB
Furnace brazing	FB
Induction brazing	IB
Resistance brazing	RB
Dip brazing	DB
Block brazing	BB
Flow brazing	FLB
Infrared brazing	IRB
Diffusion brazing	DFB
Arc brazing	AB
Resistance welding	RW
Flash welding	FW
Upset welding	UW
Percussion welding	PEW
Induction welding	IW
Projection welding	RPW
Resistance spot welding	RSW
Resistance seam welding	RSEW
Arc welding	AW
Bare metal–arc welding	BMAW
Stud welding	SW
Submerged arc welding	SAW
Gas tungsten–arc welding	GTAW
Gas metal–arc welding	GMAW
Atomic hydrogen welding	AHW
Shielded metal–arc welding	SMAW
Twin carbon–arc welding	TCAW
Carbon–arc welding	CAW
Gas carbon–arc welding	GCAW
Shielded carbon–arc welding	SCAW
Flux cored arc welding	FCAW
Plasma arc welding	PAW
Oxyfuel gas welding	OFW
Pressure gas welding	PGW
Oxy–hydrogen welding	OHW
Oxyacetylene welding	OAW
Air–acetylene welding	AAW
Other Welding	
Electron beam welding	EBW
Electroslag welding	ESW
Flow welding	FLOW
Induction welding	IW
Laser beam welding	LBW
Thermit welding	TW

Table A–2. Designation Of Cutting Processes By Letters

Cutting Process	Letter Designation
Arc cutting	AC
Air–carbon–arc cutting	AAC
Carbon–arc cutting	CAC
Metal–arc cutting	MAC
Oxygen cutting	OC
Chemical flux cutting	FOC
Metal powder cutting	POC
Arc–oxygen cutting	AOC
*The following suffixes may be used to indicate the methods of applying above processes:	
Automatic cutting	AU
Machine cutting	ME
Manual cutting	MA
Semi–automatic cutting	SA

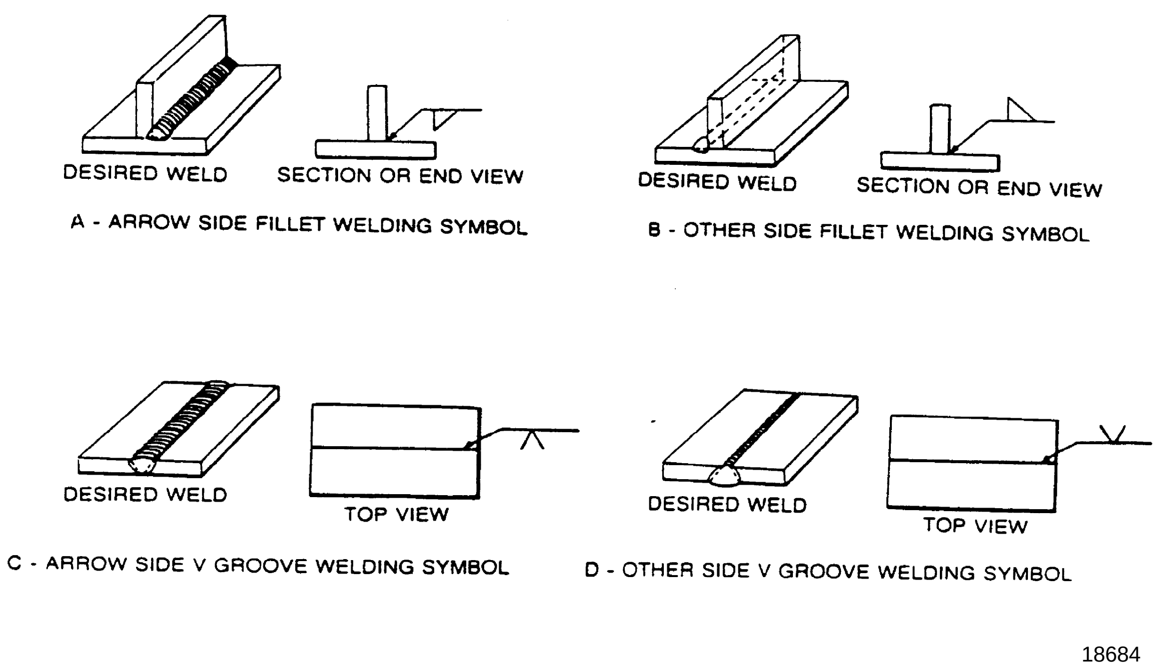


Figure A–3. Arrow Location Significance

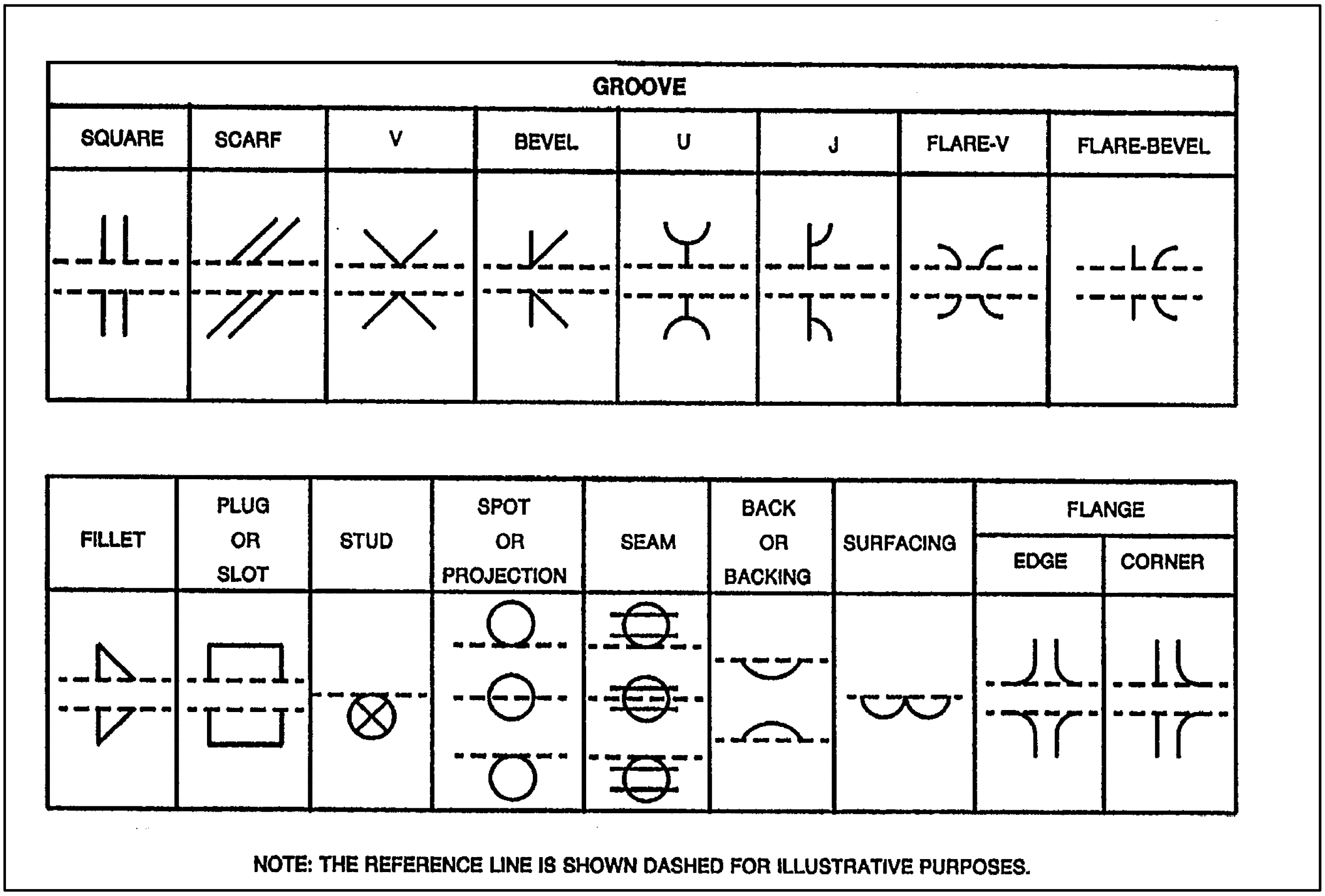


Figure A–4. Fillet and Groove Welding Symbols Denoting Location of the Weld

c. Welds on both sides of the joint shall be shown by placing weld symbols on both sides of the reference line, toward and away from the reader.

d. Resistance spot, resistance seam, flash and upset weld symbols have no arrow side or other side significance in themselves, although supplementary symbols used in conjunction with these symbols may have such significance. For example: the flush contour symbol is used in conjunction with the spot and seam symbols to show that the exposed surface of one member of the joint is to be flush. Resistance spot, resistance seam, flash and upset weld symbols shall be centered on the reference line.

A.6. The following are process codes used on General Electric drawings and are located in the tail of the weld symbol.

P8B Metal Arc, Coated Electrode – In this process, the heat is obtained from an arc formed between the work and a coated metal electrode which supplies molten filler metal to the joint. The coating of the electrode consists of a flux which protects the weld metal.

P8E Gas Welding – In this process, heat is produced by a gas flame. Flux can be used for protection of the molten puddle.

P8F Submerged Arc – In this process, heat is produced by an electric arc between a consumable bare– metal electrode and the work. Shielding is provided by a blanket of granular flux over the weld preparation.

P8G Gas–Shielded Tungsten Arc – In this process, heat is obtained from an arc between a tungsten electrode and the work in a shielding atmosphere of inert gas.

P8G Gas–Shielded Tungsten Arc – In this process, heat is obtained from an arc between a tungsten electrode and the work in a shielding atmosphere of inert gas.

P8J Gas–Shielded Metal Arc – In this process, heat is obtained from an electric arc between a consumable electrode and the work in a shielding atmosphere of inert gas.

P8K Electron Beam Welding – Electron beam welding is a fusion joining process in which the work piece is bombarded with a dense focused stream of high velocity electrons where the kinetic energy of the electron particles is transformed into heat upon work–piece impact. Electron beam power is developed in a gun under high vacuum; however, actual welding can be performed either in vacuum (usually) or in the atmosphere.

NOTE

Use of the P8P Plasma Arc melt– in (non–keyhole) process mode is permitted as an alternate to the P8G (TIG) process, unless otherwise prohibited.

P8P Plasma Arc – In this process, heat is obtained from an electric arc in a highly ionized gas called a plasma. The arc may be either transferred (between electrode and work) or non–transferred (between electrodes within the torch). Inert gas is used as the shielding medium.

NOTE

When general process designation P9 is shown in the tail of the welding symbol, any of the brazing processes described above may be used. If the words ”braze weld” are shown in the tail, the same is true. ”Braze weld” is brazing without the requirement of capillary action to draw filler metal into the joint.

P9B Resistance Brazing – A process in which the brazing heat is obtained from resistance to the flow of electric current in a circuit of which the work is a part.

P9D Induction Brazing – A process in which the brazing heat is obtained from resistance of the work to the flow of an induced electric current from a surrounding coil.

P9E Arc Brazing – A process in which the brazing heat is obtained from an electric arc.

P9F Furnace Brazing – A process in which the brazing heat is obtained by placing the prepared work in a furnace.

P9G Gas–Torch–Brazing – A process in which the brazing heat is obtained from gas flame(s).

P9H Metal–Bath Brazing – A process in which the brazing heat is obtained from a bath of molten filler material.

P9J Flux–Bath Brazing – **A** process in which the brazing heat is obtained from a bath of molten flux.

P9K Heat Lamp Brazing – In heat lamp brazing, joining or coalescence of metallic materials is produced above 800–F **(**427–C) by use of radiant heat obtained from high temperature bulbs or lamps. Lamp heat output energy is usually focused on the workpiece by reflectors. Atmospheres surrounding the brazing alloy and base metal is usually obtained by use of a flux, inert gas or a combination of both.

APPENDIX B

SPECIFIC BASE METALS FOR BASE METAL GROUPS

B.1 GENERAL.

The classification of metals by base metal groups is presented in table B–1. Some of the groups have subscript letters that divide groups into subgroups. This means that welders who certify in higher lettered subgroups are automatically certified in the lower lettered subgroups. For example, certifying in group IIb metals automatically certifies the welder in group IIa metals. The table also lists the metals by its Unified Number and common designators. For example; UNS G41300 equate to AISI 4130 alloy steel and UNS S41000 equates to 410 stainless steel.

B.2 METAL GROUPINGS.

The complete listing of metal groups by base metal is provided in Table B–1. Welders may certify or recertify in any metal listed in each group. Weld schools are generally set up with a specific selection of metal groups and certified welders may choose to use those metals for recertification.

Table B–1. Classification of Metals by Base Metal Groups

Base Metals Group Ia. Carbon Steels					
UNS	**ASTM Specification**	**AISI**	**SAE**	**AMS No.**	**Common Name**
G10060	A29, A510, A545	1006	J403		Carbon Steel
G10080	A29, A510, A519	1008	J403		Carbon Steel
G10090	A29, A510, A519	1009	J403		Carbon Steel
G10100	A29, A510, A519	1010	J403	5040	Carbon Steel
G10110	A29, A510, A519	1011	J403		Carbon Steel
G10120	A29, A510, A519	1012	J403		Carbon Steel
G10130	A29, A510, A519	1013	J403		Carbon Steel
G10150	A29, A510, A519	1015	J403	5060	Carbon Steel
G10160	A29, A510, A519	1016	J403		Carbon Steel
G10170	A29, A510, A519	1017	J403		Carbon Steel
G10180	A29, A510, A519	1018	J403	5069	Carbon Steel
G10190	A29, A510, A519	1019	J403		Carbon Steel
G10200	A29, A510, A519	1020	J403	5045	Carbon Steel
G10210	A29, A510, A519	1021	J403		Carbon Steel
G10220	A29, A510, A519	1022	J403	5070	Carbon Steel

Base Metals Group Ia. Carbon Steels (Cont)					
UNS	**ASTM Specification**	**AISI**	**SAE**	**AMS No.**	**Common Name**
G10230	A29, A510, A519	1023	J403		Carbon Steel
G10250	A29, A510, A519	1025	J403	5075	Carbon Steel
G10260	A29, A510, A519	1026	J403		Carbon Steel
G10290	A29, A510, A519	1029	J403		Carbon Steel
G10300	A29, A510, A519	1030	J403		Carbon Steel
G10330	A29, A510, A519	1033	J403		Carbon Steel
G10340	A29, A510, A519	1034	J403		Carbon Steel
G10350	A29, A510, A519	1035	J403	5080	Carbon Steel
G10370	A29, A510, A519	1037	J403		Carbon Steel
G10380	A29, A510, A519	1038	J403		Carbon Steel
G10390	A29, A510, A519	1039	J403		Carbon Steel
G10400	A29, A510, A519	1040	J403		Carbon Steel
G15220	A29, A510, A510	1522	J403		Carbon Steel
G15240	A29, A510, A510	1524	J403		Carbon Steel
G15270	A29, A510, A510	1527	J403		Carbon Steel
K01200	A178, A179				Carbon Steel
K01201	A192, A226				Carbon Steel
K01501	A414				Carbon Steel
K01502	A730				Carbon Steel
K01504	A161				Carbon Steel
K01506	A539, A587				Carbon Steel
K01601	A131				Carbon Steel
K01700	A285				Carbon Steel
K01701	A662				Carbon Steel

Base Metals Group Ia. Carbon Steels (Cont)					
UNS	**ASTM Specification**	**AISI**	**SAE**	**AMS No.**	**Common Name**
K01800	A516				Carbon Steel
K01801	A131				Carbon Steel
K01802	A633				Carbon Steel
K01807	A214, A556, A557				Carbon Steel
K02000	A730				Carbon Steel
K02001	A284, A515				Carbon Steel
K02003	A633				Carbon Steel
K02004	A595				Carbon Steel
K02005	A595				Carbon Steel
K02007	A662				Carbon Steel
K02100	A516				Carbon Steel
K02101	A131				Carbon Steel
K02102	A131				Carbon Steel
K02104	A524				Carbon Steel
K02200	A285				Carbon Steel
K02201	A414				Carbon Steel
K02202	A442				Carbon Steel
K02203	A662				Carbon Steel
K02300	A131				Carbon Steel
K02400	A537				Carbon Steel
K02401	A284, A515				Carbon Steel
K02402	A442				Carbon Steel
K02403	A516				Carbon Steel
K02404	A573				Carbon Steel

Base Metals Group Ia. Carbon Steels (Cont)					
UNS	**ASTM Specification**	**AISI**	**SAE**	**AMS No.**	**Common Name**
K02500	A109				Carbon Steel
K02501	A106, A369				Carbon Steel
K02502	A570				Carbon Steel
K02503	A414				Carbon Steel
K02504	A53, A523				Carbon Steel
K02505	A414				Carbon Steel
K02506	A727				Carbon Steel
K02600	A36				Carbon Steel
K02601	A618				Carbon Steel
K02700	A516				Carbon Steel
K02701	A573				Carbon Steel
K02702	A284				Carbon Steel
K02703	A529				Carbon Steel
K02704	A414				Carbon Steel
K02705	A500				Carbon Steel
K02707	A210				Carbon Steel
K02800	A515				Carbon Steel
K02801	A285				Carbon Steel
K02802	A445				Carbon Steel
K02803	A299				Carbon Steel
K02900	A612				Carbon Steel
K03000	A500				Carbon Steel
K03002	A327				Carbon Steel
K03003	A139				Carbon Steel

Base Metals Group Ia. Carbon Steels (Cont)					
UNS	**ASTM Specification**	**AISI**	**SAE**	**AMS No.**	**Common Name**
K03004	A139				Carbon Steel
K03005	A53, A523				Carbon Steel
K03006	A106				Carbon Steel
K03007	A557				Carbon Steel
K03008	A333				Carbon Steel
K03009	A350				Carbon Steel
K03010	A139				Carbon Steel
K03011	A350				Carbon Steel
K03012	A139				Carbon Steel
K03013	A381				Carbon Steel
K03100	A31				Carbon Steel
K03101	A515				Carbon Steel
K03102	A414				Carbon Steel
K03103	A414				Carbon Steel
K03200	A696				Carbon Steel
K03300	A455				Carbon Steel
K03501	A106, A210, A234				Carbon Steel
K03502	A181				Carbon Steel
K03503	A178				Carbon Steel
K03504	A105, A695				Carbon Steel
K03505	A557				Carbon Steel
K03506	A266, A541				Carbon Steel

Base Metals Group Ia. Carbon Steels (Cont)					
UNS	**ASTM Specification**	**AISI**	**SAE**	**AMS No.**	**Common Name**
K04001	A372				Carbon Steel
K04700	A21, A383, A730				Carbon Steel
K05001	A266, A649				Carbon Steel
K05200	A21, A730				Carbon Steel

Base Metal Group Ib. Alloy Steels				
UNS	**ASTM Specification**	**AMS No.**	**MIL SPEC**	**Common Name**
G41300	A29, A331, A519	6348	MIL–S–16974	4130
G41350	A29, A331, A519	6352	MIL–S–16974	4135
G41400	A29, A519, A711	6349	MIL–S–16974	4140
G43400	A29, A331, A711	6359	MIL–S–16974	4340
G86300	A29, A331, A519	6280	MIL–S–16974	8630
K24728	A355, A579	6431	MIL–S–8949	D6AC
K44315	A579	6419	MIL–S–8844	300M
K51545	A213, A335			Alloy Steel
K61595	A213, A335			Alloy Steel
K71340	A522, A553			Alloy Steel
K81340	A522, A553			Alloy Steel
K81590	A199, A437			Alloy Steel

Base Metal Group Ib. Alloy Steels (Cont)				
UNS	**ASTM Specification**	**AMS No.**	**MIL SPEC**	**Common Name**
K90941	A182, A396			Alloy Steel
K92810	A538		MIL–S–47139	18 Ni Maraging Steel
K93601	A658			Nickel Steel, 36% Ni
T20811	A579, A681	6437	MIL–S–47086	H11

Base Metal Group IIa. Stainless Steels					
UNS	**ASTM Specification**	**AISI**	**SAE**	**AMS No.**	**Common Name**
K63198	A543, A547		J467	5526	19–9 DL
K63199			J467	5782	19–9 DX
K64299				5784	29–9
R30155	A639, A567			5376	N–155
R30590				5770	S–590
S20100	A412, A429, A666	201	J405		201
S20200	A314, A412, A666	202	J405		202
S20910	A182, A240, A249			5764	22–13–5
S21600	A240, A479, A492				216
S21603	A240, A479, A492				216L
S21900	A276, A314, A412			5561	21–6–9
S21904	A276, A314, A412			5562	21–6–0 LC
S24000	A240, A249, A269				18–3–MN
S30100	A176, A177, A554	301	J405	5517	301

Base Metal Group IIa. Stainless Steels (Cont)					
UNS	**ASTM Specification**	**AISI**	**SAE**	**AMS No.**	**Common Name**
S30200	A167, A240, A276	302	J405	5515	302
S30215	A167, A276, A314	302B	J405		302B
S30400	A167, A276, A314	304	J405	5501	304
S30403	A167, A276, A314	304L	J405	5511	304L
S30409	A182, A213, A312	304H			304H
S30451	A182, A213, A312	304N			304N
S30500	A167, A240, A249	305	J405	5514	305
S30800	A167, A240, A314	308	J405		308
S30900	A167, A240, A314	309	J405		309
S30908	A167, A240, A314	309S	J405	5523	309S
S31000	A167, A182, A314	310	J405		310
S31008	A167, A240, A314	310S	J405	5521	310S
S31500	A669				
S31600	A167, A182, A213	316	J405	5524	316
S31603	A167, A182, A213	316L	J405	5507	316L
S31609	A182, A213, A240				316H
S31651	A182, A213, A240	316N			316N
S31700	A167, A240, A314	317	J405		317
S31703	A167, A240	317L			317L
S32100	A167, A240	321	J405	5510	321
S32109	A182, A240				321H

Base Metal Group IIa. Stainless Steels (Cont)					
UNS	**ASTM Specification**	**AISI**	**SAE**	**AMS No.**	**Common Name**
S32900	A268, A511	329			329
S33100	A182				F–10
S34700	A182, A213, A249	347	J405	5512	347
S34709	A182, A213, A249				347H
S34800	A182, A213, A249	348	J405		348
S34809	A182, A213, A249				348H
S35000	A579, A693		J467	5546	AM 350
S35500	A564, A579, A693		J467	5547	AM 355
S38100	A167, A213, A240				18–18–2
S40300	A176, A276, A314	403	J405		403
S40500	A176, A240, A314	405	J405		405
S40900	A176, A286, A651	409	J405		409
S41000	A176, A268, A314	410	J405	5504	410
S41008	A176, A240, A473				410S
S41040	A479			5509	XM–30
S41800	A565		J467	5508	Greek Ascoloy
S42000	A276, A314, A473	420	J405	5506	420
S42200	A565	422	J467	5655	422
S42900	A182, A240, A314	429	J405		429
S43000	A182, A240, A314	430	J405	5503	430
S43035	A240, A268, A651	439			HWT, Aqualloy

Base Metal Group IIa. Stainless Steels (Cont)					
UNS	**ASTM Specification**	**AISI**	**SAE**	**AMS No.**	**Common Name**
S44300	A176, A268, A511				443
S44400	A176, A240, A268				444
S44600	A176, A268, A314	446	J405		446
S45000	A564, A693, A705			5763	Custom 450
S45500	A313, A564, A705			5578	Custom 455

Base Metal Group IIb. Precipitation Hardening Stainless Steels				
UNS	**ASTM Specification**	**AMS No.**	**MIL SPEC**	**Common Name**
S13800	A564, A693, A705	5629		PH 13–8 Mo
S15500	A564, A693, A705		5658	15–5 PH
S15700	A564, A693, A705	5520	MIL–S–8955	PH 15–7 Mo
S16800	A376, A430			16–8–2–H
S17400	A564, A693, A705	J467	5604	17–4 PH
S17700	A564, A693, A705	5528	MIL–S–25043	17–7 PH
S66286	A453, A638	5525		A286
S66545	A453	5543		W545

Base Metal Group IIIa. Nickel and Nickel–Base Alloys				
UNS	**ASTM Specification**	**AMS No.**	**MIL SPEC**	**Common Name**
N02200	B160, B161, B366			Nickel 200
N02201	B160, B161, B366	5553		Nickel 201

Base Metal Group IIIa. Nickel and Nickel–Base Alloys (Cont)				
UNS	**ASTM Specification**	**AMS No.**	**MIL SPEC**	**Common Name**
N04400	B127, B163, B164	4544	MIL–N–24106	Monel 400
N06002	B366, B435, B622	5390		Hasteloy X
N06007	B366, B581, B619			Hasteloy G
N06455	B574, B575, B619			Hasteloy C–4
N06600	B136, B166, B366	5540		Inconel 600
N06625	B366, B443, B705	5401	MIL–E–21562	Inconel 625
N06975	B366, B581, B619			Hasteloy G–2
N08020	B366, B462, B464			Carpenter 20Cb3
N08320	B366, B620, B622			Haynes 20 Mod
N08330	B366, B511, B710	5592		RA330
N08800	B366, B514, B564	5766		Incoloy 800
N08810	B366, B514, B564			Incoloy 800H
N08825	B163, B423, B704			Incoloy 825
N08904	B625, B649, B673			Ni–Cr–Mo Alloy
N10001	B333, B335, B619	5396	MIL–R–5031	Hasteloy B
N10002	A494, A567	5388	MIL–R–5031	Hasteloy C
N10003	B366, B434, B573	5607		Hasteloy N
N10276	B366, B574, B619			Hasteloy 276
N10665	B366, B619, B626			Hasteloy B2

Base Metal Group IIIb. Precipitation Hardening Nickel–Base Alloys				
UNS	**ASTM Specification**	**AMS No.**	**MIL SPEC**	**Common Name**
				Rene 77
				Rene 80
				Udimet 700
N05500		4676	MIL–N–24549	Monel K500
N06601		5715		Inconel 601
N07001	B637	5544		Waspaloy
N07041		5399		Rene 41
N07252	B637	5551		M252
N07500	A567, B637	5384		Udimet 500
N07718	B637, B670	5383	MIL–N–24469	Inconel 718
N07750	B637	5384	MIL–N–24114	Inconel x750
N09706		5605		Inconel 706
N09901		5660		Incoloy 901

Base Metal Group IV. Aluminum and Aluminum–Base Alloys					
UNS	**ASTM Specification**	**AMS No.**	**MIL SPEC**	**AA**	**Common Name**
A03560	B26, B108	4217	MIL–F–3922	356.0	356
A91060	B209, B210, B234	4000		1060	1060
A91100	B209, B210, B241	4001	MIL–A–52177	1100	1100
A92014	B209, B210, B241	4028	MIL–A–22771	2014	2014
A92219	B209, B211, B241	4031	MIL–A–22771	2219	2219

Base Metal Group IV. Aluminum and Aluminum–Base Alloys (Cont)					
UNS	**ASTM Specification**	**AMS No.**	**MIL SPEC**	**AA**	**Common Name**
A93003	B209, B211, B241	4006	MIL–A–81596	3003	3003
A93004	B209, B221, B548			3004	3004
A95052	B209, B221, B404	4004	MIL–A–81596	5052	5052
A95083	B209, B241, B547	4056	QQ–A–200/4	5083	5083
A95086	B209, B241, B547		QQ–A–200/5	5086	5086
A95154	B209, B210, B547	4018	MIL–C–26094	5154	5154
A95254	B209, B241, B548			5254	5254
A95454	B209, B241, B548		QQ–A–200/6	5454	5454
A95456	B209, B241, B548		QQ–A–200/7	5456	5456
A95652	B209, B241, B548			5652	5652
A96061	B209, B241, B548	4009	QQ–A–200/8	6061	6061
A96063	B210, B241, B361	4156	QQ–A–200/9	6063	6063

Base Metals Group V. Magnesium–Base Alloys					
UNS	**ASTM Specification**	**SAE**	**AMS No.**	**MIL SPEC**	**Common Name**
M10100	B80, B275, B403	J465	4455	QQ–M–55	AM100A
M11311	B90, B107, B275	J466	4375	QQ–M–31	AZ31B
M11610	B91, B107, B275	J466	4350	QQ–M–31	AZ61A
M11800	B91, B107, B275	J466	4360	QQ–M–31	AZ80A
M11910	B93, B94, B275	J465	4490	QQ–M–38	AZ91A
M11920	B93, B94, B275	J465	4434	QQ–M–55	AZ92A

Base Metals Group V. Magnesium–Base Alloys (Cont)					
UNS	**ASTM Specification**	**SAE**	**AMS No.**	**MIL SPEC**	**Common Name**
M12330	B80, B199, B275	J465	4396	QQ–M–55	EZ33A
M13210	B90, B91, B275	J466	4363	QQ–M–40	HM21A
M13310	B80, B90, B275	J466	4384	QQ–M–55	HK31A
M13312	B275	J466	4388	MIL–M–8916	HM31A
M13320	B80, B275	J465	4447	QQ–M–55	HZ32A
M14141	B90	J466	4386	MIL–M–46130	LA141A
M16620	B80, B275	J465	4438	QQ–M–56	ZH62A
M18220	B80, B199, B403	J465	4418	QQ–M–56	QE22A

Base Metal Group VI. Titanium and Titanium–Base Alloys				
UNS	**ASTM Specification**	**AMS No.**	**MIL SPEC**	**Common Name**
R50250	B265, B337, B338		MIL–T–81556	Titanium CP
R50400	B265, B337, B338	4902	MIL–T–81556	Titanium CP
R50550	B265, B337, B338	4900	MIL–T–81556	Titanium CP
R52400	B265, B337, B338			Titanium
R54520	B265, B348, B367	4910	MIL–T–9046	Ti–5Al–2.5Sn
R54620		4919	MIL–T–9046	Ti–6Al–2Sn–4Ar–2Mo
R54810		4915	MIL–T–9046	Ti–8Al–1Mo–1V
R56210			MIL–T–9046	Ti–6Al–2Sn–4Ar–6Mo
R56260		4981	MIL–T–9047	Ti–6Al–2Cb–1Ta–1Mo
R56320	B337, B338	4943	MIL–T–9047	Ti–3Al–2.5V

Base Metal Group VI. Titanium and Titanium–Base Alloys (Cont)				
UNS	**ASTM Specification**	**AMS No.**	**MIL SPEC**	**Common Name**
R56400	B265, B348, B367	4905	MIL–T–9047	Ti–6Al–4V
R56620		4918	MIL–T–9047	Ti–6Al–6V–2Sn
R58640			MIL–T–9047	Ti–3Al–8V–6Cr–4Mo–4Zr

Base Metal Group VII. Cobalt–Base Alloys				
UNS	**ASTM Specification**	**AMS No.**	**MIL SPEC**	**Common Name**
R30006		5373	MIL–R–17131	Stellite 6
R30021	A567	5385		Stellite 21
R30023		5375		Stellite 23
R30027		5378		Stellite 27
R30030		5380		Stellite 30
R30031	A567	5382		Stellite 31
R30188		5608		HS188
R30605	F90	5537	MIL–R–5031	L605
R30816	A461, A639	5534		S816

GLOSSARY

Section I. GENERAL

Glossary 1. .General

This glossary of welding terms has been prepared to acquaint welding personnel with nomenclatures and definitions of common terms related to welding and allied processes, methods, techniques, and applications.

Glossary 2. Scope.

The welding terms listed in section II are those used to describe and define the standard nomenclatures and language used in this manual. This glossary is a very important part of the manual and should be carefully studied and regularly referred to for better understanding of common welding terms and definitions. Terms and nomenclatures listed herein are grouped in alphabetical order.

Section II. WELDING TERMS

A

ACTUAL THROAT: The shortest distance between the weld root and the face of a fillet weld.

AIR CARBON ARC CUTTING (AAC): An arc cutting process that melts base metals by the heat of a carbon arc and removes the molten metal by a blast of air.

ARC BLOW: The deflection of an electric arc from its normal path because of magnetic forces.

ARC CUTTING (AC): A group of cutting processes that melt the base metal with the heat of an arc between an electrode and the base metal.

ARC CUTTING GUN (GAS METAL ARC CUTTING): device used in semiautomatic, machine and automatic arc cutting to transfer current, guide the consumable electrode and direct the shielding gas.

ARC FORCE: The axial force developed by an arc plasma.

ARC GOUGING: An arc cutting process variation used to form a bevel or groove.

ARC SEAM WELD: A seam weld made by an arc welding process.

ARC SPOT WELD: A spot weld made by an arc welding process.

ARC STRIKE: A discontinuity consisting of any localized remelted metal, heat affected metal, or change in the surface profile of any part of a weld or base metal resulting from an arc.

ARC WELDING (AW): A group of welding processes that produces coalescence of metals by heating them with an arc, with or without the application of pressure and with or without the use of filler metal.

ARC WELDING ELECTRODE: A component of the welding circuit through which current is conducted and which terminates at the arc.

ARC WELDING GUN: A device used in semiautomatic, machine and automatic arc welding to transfer current, guide the consumable electrode and direct the shielding gas.

AS–WELDED: The condition of weld metal, welded joints, and weldments after welding and prior to any subsequent thermal or mechanical treatment.

AUTOGENOUS WELD: A fusion weld made without the addition of filler metal.

AUTOMATIC WELDING: Welding with equipment that performs the welding operation without adjustment of the controls by a welding operator. The equipment may or may not load and unload the workpieces. See also machine welding.

B

BACK BEAD: A weld bead resulting from a back weld pass.

BACKFIRE: The momentary recession of the flame into the welding tip or cutting tip followed by immediate reappearance or complete extinction of the flame.

BACK GOUGING: The removal of weld metal and base metal from the other side of a partially welded joint to facilitate complete fusion and complete joint penetration upon subsequent welding from that side.

BACKHAND WELDING: A welding technique in which the flame is directed towards the completed weld.

BACKING: A material or device placed against the back side of the joint, or at both sides of a weld in electroslag and electrogas welding, to support and retain molten weld metal. The material may be partially fused or remain unfused during welding and may be either metal or nonmetal.

BACKING BEAD: A weld bead resulting from a backing pass.

BACKING FILLER METAL: A nonstandard term for consumable insert.

BACKING PASS: A weld pass made for a backing weld.

BACKING RING: Backing in the form of a ring, generally used in the welding of pipe.

BACKING SHOE: A nonconsumable backing device used in electroslag and electrogas welding.

BACKING WELD: Backing in the form of a weld.

BACKSTEP SEQUENCE: A longitudinal sequence in which weld passes are made in the direction opposite to the progress of welding.

BACK WELD: A weld made at the back of a single groove weld.

BALLING UP: The formation of globules of molten brazing filler metal or flux due to lack of wetting of the base metal.

BASE MATERIAL: The material to be welded, brazed, soldered or cut. See also base metal and substrate.

BASE METAL: The metal to be welded or cut. In alloys it is the metal present in the largest proportion.

BEAD WELD: A nonstandard term for surfacing weld.

BEVEL: An angular edge preparation.

BEVEL ANGLE: The angle formed between the prepared edge of a member and a plane perpendicular to the surface of the member.

BEVEL GROOVE WELD: A type of groove weld.

BLACKSMITH WELDING: A nonstandard term for forge welding.

BLOCK SEQUENCE: A combined longitudinal and cross–sectional sequence for a continuous multiple pass weld in which separated increments are completely or partially welded before intervening increments are welded.

BLOWHOLE: A nonstandard term for porosity.

BOTTLE: A nonstandard term for gas cylinder.

BOXING: The operation of continuing a fillet weld around a corner of a member as an extension of the principal weld.

BRAZE: A weld produced by heating an assembly to the brazing temperature using a filler metal having a liquidus above 840°F(450°C) and below the solidus of the base metal. The filler metal is distributed between the closely fitted faying surfaces of the joint by capillary action.

BRAZE INTERFACE: The interface between filler metal and base metal in a brazed joint.

BRAZEMENT: An assembly whose component parts are joined by brazing.

BRAZER: One who performs a manual or semiautomatic brazing operation.

BRAZE WELDING: A welding process variation in which a filler metal, having a liquidus above 840°F(450°C) and below the solidus of the base metal, is used. Unlike brazing, in braze welding the filler metal is not distributed in the joint by capillary action.

BRAZING (B): A group of welding processes that produce coalescence of materials by heating them to the brazing temperature in the presence of a filler metal having a liquidus above 840°F(450°C) and below the solidus of the base metal. The filler metal is distributed between the closely fitted faying surfaces of the joint by capillary action.

BRAZING ALLOY: A nonstandard term for brazing filler metal.

BRAZING FILLER METAL: The metal that fills the capillary joint clearance and has a liquidus above 840°F(450°C) but below the solidus of the base metals.

BRAZING OPERATOR: One who operates machine or automatic brazing equipment.

BRITTLE NUGGET: A nonstandard term used to describe a faying plane failure in a resistance weld peel test.

BRONZE WELDING: A nonstandard term for braze welding.

BUILDUP: A surfacing variation in which surfacing metal is deposited to achieve the required dimensions. See also BUTTERING.

BURNER: A nonstandard term for oxygen cutter.

BURNING: A nonstandard term for oxygen cutting.

BURN THROUGH: A nonstandard term for excessive melt through or a hole.

BURN THROUGH WELD: A nonstandard term for a seam weld or spot weld.

BUTTERING: A surfacing variation that deposits surfacing metal on one or more surfaces to provide metallurgically compatible weld metal for the subsequent completion of the weld. See also BUILDUP.

BUTT JOINT: A joint between two members aligned approximately in the same plane.

BUTTON: That part of a weld, including all or part of the nugget, that tears out in the destructive testing of spot, seam or projection welded specimens.

BUTT WELD: A nonstandard term for a weld in a butt joint.

C

CARBON–ARC CUTTING (CAC): An arc cutting process that severs base metals by melting them with the heat of an arc between a carbon electrode and the base metal.

CARBONIZING FLAME: A nonstandard term for reducing flame.

CAULK WELD: A nonstandard term for seal weld.

CHAIN INTERMITTENT WELD: An intermittent weld on both sides of a joint in which the weld increments on one side are approximately opposite those on the other side.

CHAMFER: A nonstandard term for bevel.

CHILL RING: A nonstandard term for backing ring.

CLAD BRAZING SHEET: A metal sheet on which one or both sides are clad with brazing filler metal.

COALESCENCE: The growing together or growth into one body of the materials being welded.

COATED ELECTRODE: A nonstandard term for covered electrode.

COEXTRUSION WELDING (CEW): A solid–state welding process that produces coalescence of the faying surfaces by heating and forcing base metals through a extrusion die.

COLD CRACK: A crack which develops after solidification is complete.

COLD SOLDERED JOINT: A joint with incomplete coalescence caused by insufficient application of heat to the base metal during soldering.

COLD WELDING (CW): A solid–state welding process in which pressure is used at room temperature to produce coalescence of metals with substantial deformation at the weld. See also diffusion welding, forge welding and hot pressure welding.

COMPLETE FUSION: Fusion which has occurred over the entire base metal surface intended for welding and between all adjoining weld beads.

COMPLETE JOINT PENETRATION: A penetration by weld metal for the full thickness of the base metal in a joint with a groove weld.

COMPLETE PENETRATION: A nonstandard term for complete joint penetration.

CONCAVITY: The maximum distance from the face of a concave fillet weld perpendicular to a line joining the weld toes.

CONE: The conical part of a gas flame next to the orifice of the tip.

CONSTRICTED ARC (PLASMA ARC WELDING AND CUTTING): A plasma arc column that is shaped by a constricting nozzle orifice.

CONSUMABLE INSERT: Preplaced filler metal that is completely fused into the joint root and becomes part of the weld.

CONTACT RESISTANCE (RESISTANCE WELDING): Resistance to the flow of electric current between two workpieces or an electrode and a workpiece.

CONTACT TUBE: A device which transfers current to a continuous electrode.

CONVEXITY: The maximum perpendicular distance from the face of a convex fillet weld to a line joining the toes.

COPPER BRAZING: A nonstandard term for brazing with a copper filler metal.

CORNER–FLANGE WELD: A flange weld with only one member flanged at the joint.

CORNER JOINT: A joint between two members located approximately at right angles to each other in the form of an L.

CORONA (RESISTANCE WELDING): The area sometimes surrounding the nugget of a spot weld at the faying surface which provides a degree of solid–state welding.

CO_2 WELDING: A nonstandard term for gas metal arc welding.

COVERED ELECTRODE: A composite filler metal electrode consisting of a core of a bare electrode or metal cored electrode to which a covering sufficient to provide a slag layer on the weld metal has been applied. The covering may contain material providing such functions as shielding from the atmosphere, deoxidization and arc stabilization and can serve as a source of metallic additions to the weld.

CRACK: A fracture type discontinuity characterized by a sharp tip and high ratio of length and width to opening displacement.

CRATER: A depression at the termination of an arc weld.

CUTTING ATTACHMENT: A device for converting an oxyfuel gas welding torch into an oxygen cutting torch.

CUTTING BLOWPIPE: A nonstandard term for cutting torch.

CUTTING NOZZLE: A nonstandard term for cutting tip.

CUTTING TIP: The part of an oxygen cutting torch from which the gases issue.

CUTTING TORCH (ARC): A device used in air carbon arc cutting, gas tungsten arc cutting, and plasma arc cutting to control the position of the electrode, to transfer current, and to control the flow of gases.

CUTTING TORCH (OXYFUEL GAS): A device used for directing the preheating flame produced by the controlled combustion of fuel gases and to direct and control the cutting oxygen.

CYLINDER MANIFOLD: A multiple header for interconnection of gas or fluid sources with distribution points.

D

DEFECT: A discontinuity or discontinuities that by nature or accumulated effect (for example, total crack length) render a part or product unable to meet minimum applicable acceptance standards or specification. This term designates rejectability. See also discontinuity and flaw.

DEPOSITED METAL: Filler metal that has been added during a welding operation.

DEPOSITION EFFICIENCY (ARC WELDING): The ratio of the weight of deposited metal to the net weight of filler metal consumed, exclusive of stubs.

DEPOSITION SEQUENCE: A nonstandard term for weld pass sequence.

DEPTH OF FUSION: The distance that fusion extends into the base metal or previous pass from the surface melted during welding.

DIFFUSION BRAZING (DFB): A solid–state welding process that produces coalescence of the faying surfaces by the application of pressure at elevated temperature. The process does not involve macroscopic deformation, melting or relative motion of the workpieces. A solid filler metal may or may not be inserted between the faying surfaces. See also cold welding, forge welding and hot pressure welding.

DIFFUSION WELDING (DFW): A solid–state welding process that produces coalescence of the faying surfaces by the application of pressure at elevated temperature. The process does not involve macroscopic deformation, melting or relative motion of the workpieces. A solid filler metal may or may not be inserted between the faying surfaces. See also cold welding, forge welding and hot pressure welding.

DILUTION: The change in chemical composition of a welding filler metal caused by the admixture of the base metal or previous weld metal in the weld bead. It is measured by the percentage of base metal or previous weld metal in the weld bead.

DIP BRAZING (DB): A brazing process using the heat furnished by a molten chemical or metal bath. When a molten chemical bath is used, the bath may act as a flux. When a molten metal bath is used, the bath provides the filler metal.

DIRECT CURRENT ELECTRODE NEGATIVE (DCEN): The arrangement of direct current arc welding leads in which the workpiece is the positive pole and the electrode is the negative pole of the welding arc.

DIRECT CURRENT ELECTRODE POSITIVE (DCEP): The arrangement of direct current arc welding leads in which the workpiece is the negative pole and the electrode is the positive pole of the welding arc.

DIRECT CURRENT REVERSE POLARITY: A nonstandard term for direct current electrode positive.

DIRECT CURRENT STRAIGHT POLARITY: A nonstandard term for direct current electrode negative.

DISCONTINUITY: An interruption of the typical structure of a weldment, such as a lack of homogeneity in the mechanical, metallurgical or physical characteristics of the material or weldment. A discontinuity is not necessarily a defect. See also DEFECT and FLAW.

DOWNHAND: A nonstandard term for flat position.

DRAG (THERMAL CUTTING): The offset distance between the actual and straight line exit points of the gas stream or cutting beam measured on the exit surface of the material.

E

EDGE–FLANGE WELD: A flange weld with two members flanged at the location of welding.

EDGE JOINT: A joint between the edges of two or more parallel or nearly parallel members.

EDGE WELD: A weld in an edge joint.

EDGE WELD SIZE: The weld metal thickness measured at the weld root.

EFFECTIVE THROAT: The minimum distance minus any convexity between the weld root and the face of a fillet weld.

ELECTRODE: See welding electrode.

ELECTRODE EXTENSION: For gas metal arc welding, flux cored arc welding and submerged arc welding, the length of unmelted electrode extending beyond the end of the contact tube.

ELECTRODE FORCE: The force between the electrodes in making spot, seam or projection welds by resistance welding.

ELECTRODE HOLDER: A device used for mechanically holding the electrode and conducting current to it.

ELECTRODE INDENTATION (RESISTANCE WELDING): The depression formed on the surface of workpieces by electrodes.

ELECTRODE LEAD: The electrical conductor between the source of arc welding current and the electrode holder.

END RETURN: A nonstandard term for boxing.

F

FACE REINFORCEMENT: Weld reinforcement at the side of the joint from which welding was done. (See also root reinforcement.)

FAYING SURFACE: That surface of a member that is in contact with another member to which it is joined.

FERRITE NUMBER: An arbitrary, standardized value designating the ferrite content of an austenitic stainless steel weld metal. It should be used in place of percent ferrite or volume percent ferrite on a direct replacement basis.

FILLER METAL: The metal to be added in making a welded, brazed or soldered joint. See also brazing filler metal, consumable insert, solder, welding electrode, welding rod and welding wire.

FILLER WIRE: A nonstandard term for welding wire.

FILLET WELD: A weld of approximately triangular cross section, as used in a lap joint, tee joint or corner joint, joining two surfaces at approximately right angles to each other.

FILLET WELD BREAK TEST: A test in which the specimen is loaded so that the weld root is in tension.

FILLET WELD LEG: The distance from the joint root to the toe of the fillet weld.

FILLET WELD SIZE: For equal leg fillet welds, the leg lengths of the largest isosceles right triangle which can be inscribed within the fillet weld cross–section. For unequal leg fillet welds, the leg lengths of the largest right triangle that can be inscribed within the fillet weld cross–section.

FILLET WELD THROAT: See actual throat, effective throat, and theoretical throat.

FIRECRACKER WELDING: A variation of the shielded metal arc welding process in which a length of covered electrode is placed along the joint in contact with the workpieces. During the welding operation, the stationary electrode is consumed as the arc travels the length of the electrode.

FISHEYE: A discontinuity found on the fracture surface of a weld in steel that consists of a small pore or inclusion surrounded by an approximately round, bright area.

FLAME CUTTING: A nonstandard term for oxygen cutting.

FLAME PROPAGATION RATE: The speed at which a flame travels through a mixture of gases.

FLANGE WELD: A weld made on the edges of two or more members to be joined, usually light gage metal, at least one of the members being flanged.

FLANGE WELD SIZE: The weld metal thickness measured at the weld root.

FLARE–BEVEL–GROOVE WELD: A weld in a groove formed by a member with a curved surface in contact with a planar member.

FLARE–V–GROOVE WELD: A weld in a groove formed by two members with curved surfaces.

FLASH: Material that is expelled from a flash weld prior to the upset portion of the welding cycle.

FLASH BUTT WELDING: A nonstandard term for flash welding.

FLAT POSITION: The welding position used to weld from the upper side of the joint; the face of the weld is approximately horizontal.

FLAW: A near synonym for discontinuity but with an undesirable connotation. See also defect and discontinuity.

FLUX: Material used to prevent, dissolve or facilitate removal of oxides and other undesirable surface substances.

FLUX CORED ARC WELDING (FCAW): An arc welding process that produces coalescence of metals by heating them with an arc between a continuous filler metal electrode and the work. Shielding is provided by a flux contained within the tubular electrode. Additional shielding may or may not be obtained from an externally supplied gas or gas mixture. See also flux cored electrode.

FLUX CORED ELECTRODE: A composite filler metal electrode consisting of a metal tube or other hollow configuration containing ingredients to provide such functions as shielding atmosphere, deoxidization, arc stabilization, and slag formation. Minor amounts of alloying materials may be included in the core. External shielding may or may not be used.

FOREHAND WELDING: A welding technique in which the welding torch or gun is directed toward the progress of welding.

FORGE WELDING (FOW): A solid–state welding process that produces coalescence of metals by heating them in air in a forge and by applying pressure or blows sufficient to cause permanent deformation at the interface. See also cold welding, diffusion welding, hot pressure welding and roll welding.

FURNACE BRAZING (FB): A brazing process in which the workpieces are placed in a furnace and heated to the brazing temperature.

FUSION: The melting together of filler metal and base metal (substrate), or of base metal only, which results in coalescence. See also depth of fusion.

FUSION FACE: A surface of the base metal that will be melted during welding.

FUSION WELDING: Any welding process that used fusion of the base metal to make the weld.

FUSION ZONE: The area of base metal melted as determined on the cross–section of a weld.

G

GAP: A nonstandard term for joint clearance and root opening.

GAS BRAZING: A nonstandard term for torch brazing.

GAS CUTTER: A nonstandard term for oxygen cutter.

GAS CUTTING: A nonstandard term for oxygen cutting.

GAS CYLINDER: A portable container used for transportation and storage of a compressed gas.

GAS GOUGING: A nonstandard term for oxygen gouging.

GAS METAL–ARC WELDING (GMAW): An arc welding process that produces coalescence of metals by heating them with an arc between a continuous filler metal electrode and the workpieces. Shielding is obtained entirely from an externally supplied gas.

GAS POCKET: A nonstandard term for porosity.

GAS REGULATOR: A device for controlling the delivery of gas at some substantially constant pressure

GAS SHIELDED ARC WELDING: A general term used to describe flux cored arc welding (when gas shielding is employed), gas metal arc welding and gas tungsten arc welding.

GAS TORCH: A nonstandard term for cutting torch and welding torch.

GAS TUNGSTEN–ARC WELDING (GTAW): An arc welding process that produces coalescence of metals by heating them with an arc between a tungsten electrode (nonconsumable) and the workpieces. Shielding is obtained from a gas. Pressure may or may not be used and filler metal may or may not be used.

GAS WELDING: A nonstandard term for oxyfuel gas welding.

GLOBULAR TRANSFER (ARC WELDING): The transfer of molten metal in large drops from a consumable electrode across the arc. See also short circuiting transfer and spray transfer.

GOUGING: The forming of a bevel or groove by material removal. See also arc gouging, back gouging and oxygen gouging.

GROOVE ANGLE: The total included angle of the groove between workpieces.

GROOVE FACE: That surface of a member included in the groove.

GROOVE RADIUS: The radius of a J or U groove.

GROOVE WELD: A weld made in a groove between the workpieces.

GROOVE WELD SIZE: The joint penetration of a groove weld.

GROOVE WELD THROAT: A nonstandard term for groove weld size.

GROUND CONNECTION: An electrical connection of the welding machine frame to the earth for safety. See also workpiece connection and workpiece lead.

GROUND LEAD: A nonstandard term for workpiece lead.

H

HAMMER WELDING: A nonstandard term for cold welding and forge welding.

HEAT AFFECTED ZONE: That portion of the base metal that has not been melted, but whose mechanical properties or microstructure have been altered by the heat of welding, brazing, soldering or cutting.

HORIZONTAL FIXED POSITION (PIPE WELDING): The position of a pipe joint in which the axis of the pipe is approximately horizontal, and the pipe is not rotated during welding.

HORIZONTAL POSITION (FILLET WELD): The position in which welding is performed on the upper side of an approximately horizontal surface and against an approximately vertical surface.

HORIZONTAL POSITION (GROOVE WELD): The position of welding in which the weld axis lies in an approximately horizontal plane and the weld face lies in an approximately vertical plane.

HORIZONTAL ROLLED POSITION (PIPE WELDING): The position of a pipe joint in which the axis of the pipe is approximately horizontal and welding is performed in the flat position by rotating the pipe.

HOT CRACK: A crack that develops during solidification.

I

IMPULSE (RESISTANCE WELDING): A group of pulses occurring on a regular frequency separated only by an interpulse time.

INCLINED POSITION: The position of a pipe joint in which the axis of the pipe is at an angle of approximately 45 degrees to the horizontal, and the pipe is not rotated during welding.

INCLINED POSITION (WITH RESTRICTION RING): The position of a pipe joint in which the axis of the pipe is at an angle of approximately 45 degrees to the horizontal, and a restriction ring is located near the joint. The pipe is not rotated during welding.

INCLUDED ANGLE: A nonstandard term for groove angle.

INDUCTION BRAZING (IB): A brazing process in which the heat required is obtained from the resistance of the workpieces to induced electric current.

INERT GAS: A gas that normally does not combine chemically with the base metal or filler metal. See also protective atmosphere.

INERT GAS METAL ARC WELDING: A nonstandard term for gas metal arc welding.

INERT GAS TUNGSTEN ARC WELDING: A nonstandard term for gas tungsten arc welding.

INTERPASS TEMPERATURE: In a multipass weld, the lowest temperature of the deposited weld metal before the next pass is started.

J

JOINT: The junction of members or the edges of members which are to be joined or have been joined.

JOINT CLEARANCE: The distance between the faying surfaces of a joint. In brazing, this distance is referred to as that which is present before brazing, at the brazing temperature or after brazing is completed.

JOINT EFFICIENCY: The ratio of the strength of a joint to the strength of the base metal, expressed in percent.

JOINT PENETRATION: The depth a weld extends from its fact into a joint, exclusive of reinforcement.

JOINT ROOT: That portion of a joint to be welded where the members approach closest to each other. In cross–section, the joint root may be either a point, a line, or an area.

JOINT TYPE: A weld joint classification based on the five basic arrangement of the component parts such as butt joint, corner joint, edge joint, lap joint and T–joint.

K

KERF: The space from which metal has been removed by a cutting process.

L

LAMELLAR TEAR: A terrace–like fracture in the base metal with a basic orientation parallel to the wrought surface. It is caused by the high stress in the thickness direction that results from welding.

LAND: A nonstandard term for root face.

LAP JOINT: A joint between two overlapping members in parallel planes.

LASER: A device that produces a concentrated coherent light beam by stimulating electronic or molecular transitions to lower energy levels. LASER is an acronym for light amplification by stimulated emission of radiation.

LEAD BURNING: A nonstandard term for the welding of lead.

LIQUATION: The separation of a low melting constituent of an alloy from the remaining constituents, usually apparent in alloys having a wide melting range.

LOCKED–UP STRESS: A nonstandard term for residual stress.

LONGITUDINAL CRACK: A crack with its major axis orientation approximately parallel to the weld axis.

M

MACHINE WELDING: Welding with equipment that performs the welding operation under the constant observation and control of a welding operator. The equipment may or may not load and unload the workpieces. See also automatic welding.

MACROETCH TEST: A test in which the specimen is prepared with a fine finish and etched to give a clear definition of the weld.

MANUAL WELDING: A welding operation performed and controlled completely by hand. See also automatic welding, machine welding and semiautomatic arc welding.

MELT–THROUGH: Visible root reinforcement produced in a joint welded from one side.

METAL CORED ELECTRODE: A composite filler metal electrode consisting of a metal tube or other hollow configuration containing alloying materials. Minor amounts of ingredients providing such functions as arc stabilization and fluxing of oxides may be included. External shielding gas may or may not be used.

METAL ELECTRODE: A filler or nonfiller metal electrode used in arc welding or cutting that consists of a metal wire or rod that has been manufactured by any method and that is either bare or covered.

MIG WELDING: A nonstandard term for flux cored arc welding and gas arc welding.

MIXING CHAMBER: That part of a welding or cutting torch in which the gases are mixed for combustion.

MOLTEN WELD POOL: A nonstandard term for weld pool.

MULTIPORT NOZZLE (PLASMA ARC WELDING AND CUTTING): A constricting nozzle containing two or more orifices located in a configuration to achieve a degree of control over the arc shape.

N

NEUTRAL FLAME: An oxyfuel gas flame in which the portion used is neither oxidizing nor reducing. See also oxidizing flame and reducing flame..

NONTRANSFERRED ARC (PLASMA ARC WELDING AND CUTTING, AND PLASMA SPRAYING): An arc established between the electrode and the constricting nozzle. The workpiece is not in the electrical circuit.

NOZZLE: A device that directs shielding media.

NUGGET: The weld metal joint the workpieces in spot, roll spot, seam or projection welds.

NUGGET SIZE (RESISTANCE WELDING): The diameter of a spot or projection weld or width of a seam weld measured in the plane of the faying surfaces.

O

ORIFICE GAS (PLASMA ARC WELDING AND CUTTING): The gas that is directed into the torch to surround the electrode. It becomes ionized in the arc to form the plasma and issues from the orifice in the torch nozzle as the plasma jet.

OVERHEAD POSITION: The position in which welding is performed from the underside of a joint and the face of the weld is approximately horizontal.

OVERLAP: The protrusion of weld metal beyond the weld toes or weld root.

OVERLAP (RESISTANCE SEAM WELDING): The portion of the preceding weld nugget remelted by the succeeding weld.

OVERLAYING: A nonstandard term for surfacing.

OXIDIZING FLAME: An oxyacetylene flame in which there is an excess of oxygen. The unburned excess tends to oxidize the weld metal.

OXYACETYLENE WELDING (OAW): An oxyfuel gas welding process that produces coalescence of metals by heating them with a gas flame or flames obtained from the combustion of acetylene with oxygen. The process may be used with or without the application of pressure and with or without the use of filler metal.

OXYFUEL GAS CUTTING (OFC): A group of cutting processes used to sever metals by means of the chemical reaction of oxygen with the base metal at elevated temperatures. The necessary temperature is maintained By means of gas flames obtained from the combustion of a specified fuel gas and oxygen. See also oxygen cutting.

OXYFUEL GAS WELDING (OFW): A group of welding processes that produces coalescence by heating materials with an oxyfuel gas flame or flames, with or without the application of pressure, and with or without the use of filler metal.

OXYGAS CUTTING: A nonstandard term for oxygen cutting.

OXYGEN CUTTER: One who performs a manual oxygen cutting operation.

OXYGEN CUTTING (OC): A group of cutting processes used to sever or remove metals by means of the chemical reaction between oxygen and the base metal at elevated temperatures. In the case of oxidation–resistant metals, the reaction is facilitated by the use of a chemical flux or metal powder. See also chemical flux cutting, metal powder cutting, oxyfuel gas cutting, oxygen arc cutting, and oxygen lance cutting.

OXYGEN CUTTING OPERATOR: One who operates machine or automatic oxygen cutting equipment.

OXYGEN GOUGING: An application of oxygen cutting in which a chamfer or groove is formed.

OXYGEN GROOVING: A nonstandard term for oxygen gouging.

OXYGEN LANCE: A length of pipe used to convey oxygen to the point of cutting in oxygen lance cutting.

P

PARALLEL WELDING: A resistance welding secondary circuit variation in which the secondary current is divided and conducted through the workpieces and electrodes in parallel electrical paths so simultaneously form multiple resistance spot, seam or projection welds.

PARENT METAL: A nonstandard term for base metal.

PARTIAL JOINT PENETRATION: Joint penetration that is intentionally less than complete.

PENETRATION: A nonstandard term for joint penetration and root penetration.

PLASMA ARC CUTTING (PAC): An arc cutting process that severs metal by melting a localized area **with** a constricted arc and removing the molten material with a high velocity jet of hot, ionized gas issuing from the constricting orifice.

PLASMA ARC WELDING (PAW): An arc welding process which produces coalescence of metals by heating them with a constricted arc between an electrode and the workpiece (transferred arc) or the electrode and the constricting nozzle (nontransferred arc). Shielding is obtained from the hot, ionized gas issuing from the orifice which may be supplemented by an auxiliary source of shielding gas. Shielding gas may be an inert gas or a mixture of gases. Pressure may or may not be used, and filler metal may or may not be supplied.

PLENUM CHAMBER: (Plasma arc welding and cutting, and plasma spraying). The space between the inside wall of the constricting nozzle and the electrode.

PLUG WELD: A weld made in a circular hole in one member of a joint, fusing that member to another member. A fillet–welded hole is not to be construed as conforming to this definition.

POLARITY: See direct current electrode negative and direct current electrode positive.

POROSITY: Cavity type discontinuities formed by gas entrapment during solidification.

POSTHEATING: The application of heat to an assembly after welding, brazing, soldering, thermal spraying or thermal cutting. See also postweld heat treatment.

POSTWELD HEAT TREATMENT: Any heat treatment after welding.

PREHEAT: A nonstandard term for preheat temperature.

PREHEAT CURRENT (RESISTANCE WELDING): An impulse or series of impulses that occur prior to and are separated from the welding current.

PREHEAT TEMPERATURE: A specified temperature that the base metal must attain in the welding, brazing, soldering, thermal spraying or cutting area immediately before these operations are performed.

PRESSURE–CONTROLLED WELDING: A resistance welding process variation in which a number of spot or projection welds are made with several electrodes functioning progressively under the control of a pressure–sequencing device.

PROCEDURE QUALIFICATION: The demonstration that welds made by a specific procedure can meet prescribed standards.

PROCEDURE QUALIFICATION RECORD (PQR): A document providing the actual welding variables used to produce an acceptable test weld and the results of tests conducted on the weld to qualify a welding procedure specification.

PROCESS: A grouping of basic operational elements used in welding, cutting, adhesive bonding or thermal spraying.

PROJECTION WELDING (PW): A resistance welding process that produces coalescence by the heat obtained from the resistance to the flow of the welding current. The resulting welds are localized at predetermined points by projections, embossments or intersections.

PROTECTIVE ATMOSPHERE: A gas or vacuum envelope surrounding the workpieces used to prevent or facilitate removal of oxides and other detrimental surface substances

PUDDLE: A nonstandard term for weld pool.

PULL GUN TECHNIQUE: A nonstandard term for backhand welding.

PULSE (RESISTANCE WELDING): A current of controlled duration of either polarity through the welding circuit.

R

RANDOM INTERMITTENT WELDS: Intermittent welds on one or both sides of a joint in which the weld increments are made without regard to spacing.

REACTION STRESS: The residual stress which could not otherwise exist if the members or parts being welded were isolated as free bodies without connection to other parts of the structure.

REDUCING ATMOSPHERE: A chemically active protective atmosphere which at elevated temperature will reduce metal oxides to their metallic state.

REDUCING FLAME: A gas flame having a reducing effect due to excess fuel gas. See also neutral flame and oxidizing flame.

REGULATOR: A device used to reduce cylinder pressure to a suitable torch working pressure.

RESIDUAL STRESS: Stress remaining in a structure or member as a result of thermal and/or mechanical treatment.

RESISTANCE SEAM WELDING (RSEW): A resistance welding process that produces coalescence at the faying surfaces of overlapped parts progressively along a length of a joint. The weld may be made with overlapping weld nuggets, a continuous weld nugget, or by forging the joint as it is heated to the welding temperature by resistance to the flow of the welding current.

RESISTANCE SPOT WELDING (RSW): A resistance welding process that produces coalescence at the faying surfaces of a joint by the heat obtained from resistance to the flow of welding current through the workpieces from electrodes that serve to concentrate the welding current and pressure at the weld area.

RESISTANCE WELDING (RW): A group of welding processes that produces coalescence of the faying surfaces with the heat obtained from resistance of the work to the flow of the welding current in a circuit of which the work is a part, and by the application of pressure.

RESISTANCE WELDING ELECTRODE: The part(s) of a resistance welding machine through which the welding current and, in most cases, force are applied directly to the work. The electrode may be in the form of a rotating wheel, rotating roll, bar, cylinder, plate, clamp, chuck, or modification thereof.

RESISTANCE WELDING GUN: A manipulatable device to transfer current and provide electrode force to the weld area (usually in reference to a portable gun).

REVERSE POLARITY: A nonstandard term for direct current electrode positive.

ROOT: A nonstandard term for joint root and weld root.

ROOT BEAD: A weld that extends into or includes part or all of the joint root.

ROOT EDGE: A root face of zero width. See also root face.

ROOT FACE: That portion of the groove face adjacent to the joint root.

ROOT GAP: A nonstandard term for root opening.

ROOT RADIUS: A nonstandard term for groove radius.

ROOT REINFORCEMENT: Weld reinforcement opposite the side from which welding was done.

ROOT SURFACE: The exposed surface of a weld opposite the side from which welding was done.

S

SCARF JOINT: A form of butt joint.

SEAL WELD: A weld used primarily to obtain tightness and to prevent leakage.

SEAM WELD: A continuous weld made between or upon overlapping members, in which coalescence may start and occur on the faying surfaces, or may have proceeded from the outer surface of one member. The continuous weld may consist of a single weld bead or a series of overlapping spot welds. See also arc seam weld and resistance seam welding.

SECONDARY CIRCUIT: That portion of a welding machine that conducts the secondary current between the secondary terminals of the welding transformer and the electrodes, or electrode and workpiece.

SEMIAUTOMATIC ARC WELDING: Arc welding with equipment that controls only the filler metal feed. The advance of the welding is manually controlled.

SERIES WELDING: A resistance welding secondary circuit variation in which the secondary current is conducted through the workpieces and electrodes or wheels in a series electrical path to simultaneously form multiple resistance spot, seam or projection welds.

SET DOWN: A nonstandard term for upset.

SHEET SEPARATION (RESISTANCE WELDING): The gap surrounding the weld between faying surfaces, after the joint has been welded in spot, seam or projection welding.

SHIELDED METAL ARC CUTTING (SMAC): A metal arc cutting process in which metals are severed by melting them with the heat of an arc between a covered metal electrode and the base metal.

SHIELDED METAL ARC WELDING (SMAW): An arc welding process that produces coalescence of metals by heating them with an arc between a covered metal electrode and the workpieces. Shielding is obtained from decomposition of the electrode covering. Pressure is not used, and filler metal is obtained from the electrode.

SHIELDING GAS: Protective gas used to prevent atmospheric contamination.

SHORT CIRCUITING TRANSFER (ARC WELDING): Metal transfer in which molten metal from a consumable electrode is deposited during repeated short circuits. See also globular transfer and spray transfer.

SHOULDER: A nonstandard term for root face.

SHRINKAGE STRESS: A nonstandard term for residual stress.

SHRINKAGE VOID: A cavity type discontinuity normally formed by shrinkage during solidification.

SILVER ALLOY BRAZING: A nonstandard term for brazing with a silver–base filler metal.

SILVER SOLDERING: A nonstandard term for brazing with a silver–base filler metal.

SINGLE IMPULSE WELDING: A resistance welding process variation in which spot, projection or upset welds are made with a single impulse.

SINGLE–PORT NOZZLE: A constricting nozzle containing one orifice, located below and concentric with the electrode.

SINGLE–WELDED JOINT: A fusion welded joint that is welded from one side only.

SKULL: The unmelted residue from a liquated filler metal.

SLAG INCLUSION: Non–metallic solid material entrapped in the weld metal or between the weld metal and the base metal.

SLOT WELD: A weld made in an elongated hole in one member of a joint fusing that member to another member. The hole may be open at one end. A fillet welded slot is not to be construed as conforming to this definition.

SLUGGING: Adding a separate piece or pieces of material in a joint before or during welding with a resultant welded joint that does not comply with design, drawing, or specification requirements.

SPACER STRIP: A metal strip or bar prepared for a groove weld and inserted in the joint root to serve as a backing and to maintain the root opening during welding. It can also bridge an exceptionally wide root opening due to poor fit.

SPIT: A nonstandard term for flash.

SPLIT PIPE BACKING: Backing in the form of a pipe segment used for welding round bars.

SPOOL: A filler metal package consisting of a continuous length of welding wire in coil form wound on a cylinder (called a barrel) which is flanged at both ends. The flange contains a spindle hole of smaller diameter than the inside diameter of the barrel.

SPOT WELD: A weld made between or upon overlapping members in which coalescence may start and occur on the faying surfaces or may proceed from the outer surface of one member. The weld cross–section (plan view) is approximately circular.

SPRAY TRANSFER (ARC WELDING): Metal transfer in which molten metal from a consumable electrode is propelled axially across the arc in small droplets. See also globular transfer and short circuiting transfer.

STACK CUTTING: Thermal cutting of stacked metal plates arranged so that all the plates are severed by a single cut.

STAGGERED INTERMITTENT WELD: An intermittent weld on both sides of a joint in which the weld increments on one side are alternated with respect to those on the other side.

STANDOFF DISTANCE: The distance between a nozzle and the workpiece.

STICK ELECTRODE: A nonstandard term for covered electrode.

STICK ELECTRODE WELDING: A nonstandard term for shielded metal arc welding.

STICKOUT: A nonstandard term for electrode extension.

STRAIGHT POLARITY: A nonstandard term for direct current electrode negative.

STRANDED ELECTRODE: A composite filler metal electrode consisting of stranded wires that may mechanically enclose materials to improve properties, stabilize the arc or provide shielding.

STRESS RELIEF CRACKING: Intergranular cracking in the heat affected zone or weld metal that occurs during the exposure of weldments to elevated temperatures during post-weld heat treatment or high temperature service.

STRESS RELIEF HEAT TREATMENT: Uniform heating of a structure or a portion thereof to a sufficient temperature to relieve the major portion of the residual stresses, followed by uniform cooling.

STRINGER BEAD: A type of weld bead made without appreciable weaving motion. See also weave bead.

STUB: The short length of welding rod or consumable electrode that remains after its use for welding.

STUD ARC WELDING (SW): An arc welding process that produces coalescence of metals by heating them with an arc between a metal stud, or similar part, and the other workpiece. When the surfaces to be joined are properly heated, they are brought together under pressure. Partial shielding may be obtained by the use of a ceramic ferrule surrounding the stud. Shielding gas or flux may or may not be used.

STUD WELDING: A general term for joining a metal stud or similar part to a workpiece. Welding may be accomplished by arc, resistance, friction or other process with or without external gas shielding.

SUBMERGED ARC WELDING (SAW): An arc welding process that produces coalescence of metals by heating them with an arc or arcs between a bare metal electrode or electrodes and the workpieces. The arc and molten metal are shielded by a blanket of granular, fusible material on the workpieces. Pressure is not used, and filler metal is obtained from the electrode and sometimes from a supplemental source (welding rod, flux or metal granules).

SUBSTRATE: Any material to which a thermal spray deposit is applied.

SUCK–BACK: A nonstandard term for a concave root surface.

SURFACE EXPULSION: Expulsion occurring at an electrode–to–workpiece contact rather than at the faying surface.

SURFACING: The application by welding, brazing, or thermal spraying of a layer or layers of material to a surface to obtain desired properties or dimensions, as opposed to making a joint.

SURFACING MATERIAL: The material that is applied to a base metal or substrate during surfacing.

SURFACING METAL: The metal that is applied to a base metal or substrate during surfacing. See also surfacing material.

SURFACING WELD: A weld applied to a surface, as opposed to making a joint, to obtain desired properties or dimensions.

SYNCHRONOUS TIMING (RESISTANCE WELDING): The initiation of each half cycle of welding transformer primary current on an accurately timed delay with respect to the polarity reversal of the power supply.

T

TACKER: A nonstandard term for a tack welder.

TACK WELD: A weld made to hold parts of a weldment in proper alignment until the final welds are made.

THEORETICAL THROAT: The distance from the beginning of the joint root perpendicular to the hypotenuse of the largest right triangle that can be inscribed within the cross–section of a fillet weld. This dimension is based on the assumption that the root opening is equal to zero.

THERMAL STRESS: Stress resulting from nonuniform temperature distribution.

THROAT OF FILLET WELD: See actual throat, effective throat and theoretical throat.

THROAT OF GROOVE WELD: A nonstandard term for groove weld size.

TIG WELDING: A nonstandard term for gas tungsten arc welding

T–JOINT: A joint between two members located approximately at right angles to each other in the form of a T.

TORCH BRAZING (TB): A brazing process in which the heat required is furnished by a fuel gas flame.

TORCH TIP: See cutting tip and welding tip.

TRANSFERRED ARC (PLASMA ARC WELDING): A plasma arc established between the electrode and the workpiece.

TRANSVERSE CRACK: A crack with its major axis oriented approximately perpendicular to the weld axis.

TWIN CARBON ARC BRAZING: A nonstandard term for carbon arc brazing.

U

UNDERBEAD CRACK: A crack in the heat affected zone not extending to the surface of the base metal.

UNDERCUT: A groove melted into the base metal adjacent to the weld toe or weld root and left unfilled by weld metal.

UNDERFILL: A depression on the weld face or root surface extending below the adjacent surface of the base metal.

UPSET: Bulk deformation resulting from the application of pressure in welding. The upset may be measured as a percent increase in interface area, a reduction in length, a percent reduction in lap joint thickness, or a reduction in cross wire weld stack height.

UPSET BUTT WELDING: A nonstandard term for upset welding.

UPSET DISTANCE: The total loss of axial length of the workpieces from the initial contact to the completion of the weld. In flash welding, the upset distance is equal to the platen movement from the end of flash time to the end of upset.

UPSET WELDING (UW): A resistance welding process that produces coalescence over the entire area of faying surfaces or progressively along a butt joint by the heat obtained from the resistance to the flow of welding current through the area where those surfaces are in contact. Pressure is used to complete the weld.

V

VACUUM BRAZING: A nonstandard term for various brazing processes that take place in a chamber or retort below atmospheric pressure.

VERTICAL POSITION: The position of welding in which the axis of the weld is approximately vertical. In pipe welding, the pipe is in a vertical position and the welding is done in a horizontal position.

VERTICAL POSITION (PIPE WELDING): the position of a pipe joint in which welding is performed in the horizontal position and the pipe may or may not be rotated.

W

WEAVE BEAD: A type of weld bead made with transverse oscillation.

WELD: A localized coalescence of metals or nonmetals produced either by heating the materials to the welding temperature, with or without the application of pressure or by the application of pressure alone, with or without the use of filler metal.

WELDABILITY: The capacity of a material to be welded under the imposed fabrication conditions into a specific, suitably designed structure and to perform satisfactorily in the intended service.

WELD AXIS: A line through the length of a weld, perpendicular to and at the geometric center of its cross–section.

WELD BEAD: A weld deposit resulting from a pass.

WELD BONDING: A resistance spot welding process variation in which the spot weld strength is augmented by adhesive at the faying surfaces.

WELD CRACK: A crack located in the weld metal or heat affected zone.

WELDER: One who performs a manual or semiautomatic welding operation.

WELDER PERFORMANCE QUALIFICATION: The demonstration of a welder's ability to produce welds meeting prescribed standards.

WELD FACE: The exposed surface of a weld on the side from which welding was done.

WELDING: A materials joining process used in making welds.

WELDING BLOWPIPE: A nonstandard term for welding torch.

WELDING CURRENT: The current in the welding circuit during the making of a weld.

WELDING CYCLE: The complete series of events involved in the making of a weld.

WELDING ELECTRODE: A component of the welding circuit through which current is conducted and that terminates at the arc, molten conductive slag, or base metal. See also arc welding electrode, flux cored electrode, metal cored electrode, metal electrode, resistance welding electrode and stranded electrode.

WELDING GROUND: A nonstandard term for workpiece connection.

WELDING LEADS: The workpiece lead and electrode lead of an arc welding circuit.

WELDING MACHINE: Equipment used to perform the welding operation; for example, spot welding machine, arc welding machine and seam welding machine.

WELDING OPERATOR: One who operates machine or automatic welding equipment.

WELDING POSITION: See flat position, horizontal fixed position, horizontal position, horizontal rolled position, inclined position, overhead position and vertical position.

WELDING PROCEDURE: The detailed methods and practices involved in the production of a weldment. See also welding procedure specification.

WELDING PROCEDURE SPECIFICATION (WPS): A document providing in detail the required variables for a specific application to assure repeatability by properly trained welders and welding operators.

WELDING ROD: A form of welding filler metal, normally packaged in straight lengths, that does not conduct electrical current.

WELDING SEQUENCE: The order of making the welds in a weldment.

WELDING TIP: The tip of a gas torch especially adapted to welding.

WELDING TORCH (ARC): A device used in the gas tungsten and plasma arc welding processes to control the position of the electrode, to transfer current to the arc and to direct the flow of shielding and plasma gas.

WELDING WHEEL: A nonstandard term for resistance welding electrode.

WELDING WIRE: A form of welding filler metal, normally packaged as coils or spools, that may or may not conduct electrical current depending upon the welding process with which it is used. See also welding electrode and welding rod.

WELD INTERFACE: The interface between weld metal and base metal in a fusion weld, between base metals in a solid–state weld without filler metal or between filler metal and base metal in a solid–state weld with filler metal and in a braze.

WELD LINE: A nonstandard term for weld interface.

WELDMENT: An assembly whose component parts are formed by welding.

WELD METAL: That portion of a weld that has been melted during welding.

WELD PASS: A single progression of welding or surfacing along a joint or substrate. The result of a pass is a weld bead, layer or spray deposit.

WELD PASS SEQUENCE: The order in which the weld passes are made.

WELD PENETRATION: A nonstandard term for joint penetration and root penetration.

WELD POOL: The localized volume of molten metal in a weld prior to its solidification as weld metal.

WELD PUDDLE: A nonstandard term for weld pool.

WELD REINFORCEMENT: Weld metal in excess of the quantity required to fill a joint. See also face reinforcement and root reinforcement.

WELD ROOT: The points, as shown in cross–section, at which the back of the weld intersects the base metal surfaces.

WELD SIZE: See edge weld size, fillet weld size, flange weld size and groove weld size.

WELD TAB: Additional material on which the weld may be initiated or terminated.

WELD THROAT: See actual throat, effective throat and theoretical throat.